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VOLUME III
Aerodynamics and
Structures Session

HAA/NASA
ADVANCED ROTORCRAFT TECHNOLOGY
WORKSHOP

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VOLUME III

AERODYNAMICS AND STRUCTURES SESSION

VOLUME III
AERODYNAMICS AND STRUCTURES SESSION
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CHAIRMAN'S REPORT

HAA/NASA ADVANCED TECHNOLOGY WORKSHOP
AERODYNAMICS AND STRUCTURES SESSION

Volume III

CHAIRMAN	David S. Jenney	Sikorsky Aircraft
TECHNICAL SECRETARY	Robert J. Huston	NASA-Langley
<u>Subsession</u>	<u>Chairman</u>	<u>NASA Presentor</u>
Performance	W. Walls	Wayne Johnson
Acoustics	R. King	J. P. Raney
Vibration	T. Gaffey	Robert J. Huston
Composites	J. Shipley	H. Benson Dexter

Additional Presentors

Jack Landgrebe
United Technologies Research Center

William Walls
Boeing Vertol

Charles Cox
Bell Helicopter Textron

William F. White, Jr.
U.S. Army (AVRADCOM)

E. Robert Wood
Hughes Helicopters

John L. Shipley
U.S. Army (AVRADCOM)

The four basic subjects covered in this session are shown in the cover page program. Four NASA presentors were: Wayne Johnson, Phil Raney, Bob Huston and Bensen Dexter. The individual subsessions were chaired by Bill Walls of Boeing Vertol, Bob King of Hughes, Troy Gaffey of Bell and John Shipley of the Army - Langley.

We spent about two hours on each of these four subjects and handled them one-by-one. The conclusions from those two hour sessions weren't voted upon. I'm not presenting the results of a tally of that sort. This is a much-condensed summary of the consensus that seemed to come out of our discussions.

To start, we tried to relate what the users said in their talks on the first day (see Volume II) to the topics we were discussing. We kept score of how often things were mentioned - at least those things that were mentioned in the sense of being important and needing work. Figure 1 shows the matrix that results. To clarify the chart, it counts only items specifically mentioned. I don't think there's anyone who spoke for the users that would not say reliability was important, but only eight of them actually mentioned it on Wednesday. However, you note reliability came out at the top of the list. This chart has a number of interesting messages in it, and I won't try to give them all to you. For example, one of our panels is on vibration and if you listened for the speakers to ask for lower vibration, only two did that. However, if lower vibration is also a way to get better reliability, as we think it is, then eight speakers asked for that. So there is a need for translation that this chart attempts to do.

USER NEED MATRIX

	No.	ACOUSTICS	PERFORMANCE	VIBRATION	COMPOSITES
RELIABILITY	8			X	X
SPEED	6		X		
OEI PERF.	6		X		
III-3	4		X		
	5	X			
INTERNAL NOISE	3	X			X
WEIGHT	1				X
COST	3				
VIBRATION	2			X	

Figure 1

You also didn't hear speakers calling specifically for composite airframes and that was another of our panels. Again, they were asking for reliability. They did ask for reduced weight and lower cost and all of those are the payoffs of composite airframe. So it turns out if you keep score this way, all four of our subsessions were requested by the users, in our interpretation, whether the user said it quite that way or not.

Our subsession on Wednesday afternoon heard a synopsis of the NASA program as it exists now. Then, on Thursday, we went into critiquing that program. Since the plenary session didn't hear the synopsis of their program, this summary will cover, briefly, what they are doing, and then our response to that program.

Covering Aerodynamic Performance first, the NASA program was neatly divided in subsets as shown in Figure 2. It ranges from working with airfoils alone, two dimensionally, through adding the rotational effects to make a whole rotor, complete rotor performance and loads, and fuselage - rotor interactions and finally complete vehicle aerodynamics. Their program, which has many elements in it, was subdivided to cover this whole spectrum. As you'll see throughout all four of these sessions, there's been a lot of interaction prior to this meeting between industry, particularly, and NASA, and their program already reflects a lot of this interaction. So our session was marked by much more agreement than disagreement with what is planned.

NASA is doing a number of experiments using laser velocimeters. Four laser beams intersect at the tip of a rotor blade. With those four beams, they can measure two components of velocity at a point in the stream near the rotor tip

ROTORCRAFT AERODYNAMICS PROGRAM

MAJOR TASKS

2D AND 3D AERODYNAMIC PHENOMENA

AERODYNAMIC PHENOMENA OF ROTATING BLADE

ROTOR AERODYNAMIC PERFORMANCE AND LOADS

FUSELAGE AERODYNAMICS

ROTORCRAFT AERODYNAMICS

Figure 2

without disturbing the flow at that point. This is a very powerful tool being used in a variety of ways as we get into some of the tough problems of rotor aerodynamics. Another tool on site at Ames is the RSRA. A number of programs now can be launched in that direction, and we really haven't begun to invent all the ways it might be used.

Now to the critique and our interpretation of the user's requests, (Figure 3). One item that we've classified under performance and that showed up a number of times on Wednesday, was the need for real engine-out performance, for a real twin engine helicopter. Now, that might be interpreted to mean, "put in very ample power;" somebody said, "do it like the French do." Or, it might be interpreted to mean - pay attention to the performance of the aircraft in those environments where you only have one engine, and where it's critical. That's the end of it that the performance people need to address. Over the years, we've done a lot of work on hover performance and high speed performance, but if you are concerned about what happens when an engine quits in the process of takeoff and landing, that's another element of performance that really hasn't gotten much basic research attention in the past. The users kept telling us on Wednesday that that is very important. To just put in bigger engines is a partial solution at best. The aerodynamicist has a problem too, and it's a tough one. It involves all the sophistication of the problems he's been working, plus unsteady flows of the rotor, unsteady motions of the pilot's controls, and all that goes with that. So, we spiked this out since NASA doesn't have a current activity in this area (There are a few things that relate, but it really doesn't have much attention), and we kind of outlined here what should be done. To start, there's a need to develop or acquire a suitable mathematical model and simulation that can handle those problems, and to get data in wind tunnels and, hopefully, in flight to prove that those

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA AERO/STRUCT.

SUB-AREA PERFORMANCE

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
ENGINE-OUT PERFORMANCE III-7	VALIDATED LOW SPEED STEADY AND TRANSIENT PERFORMANCE ANALYSIS	EMPIRICAL METHODS USED. NO NASA ACTIVITY	<ul style="list-style-type: none"> DEVELOP SUITABLE MATH MODEL AND SIMULATION ACQUIRE LOW SPEED STEADY AND TRANSIENT WIND TUNNEL DATA. ACQUIRE RSRA TEST DATA. VALIDATE SIMULATION
FUEL EFFICIENCY <ul style="list-style-type: none"> LOW FUEL CONSUMPTION LONG RANGE REDUCED DIRECT OPERATING COST 	IMPROVE AIRCRAFT LIFT/DRAG RATIO (L/D)	<ul style="list-style-type: none"> ADVANCED ROTOR PROGRAM; STUDY OF FLOW FIELDS IN HIGH SPEED FLIGHT. COMPOSITES PROGRAM TO REDUCE WEIGHT 	ENDORSED PROGRAM
SPEED	INTEGRATED APPROACH TO POWER, NOISE, VIBRATION, LOADS, CONTROL	ADV. ROTOR AND SUPPORTING TECHNOLOGY	ALSO - DEVELOP WIND TUNNEL CAPABILITY TO MEASURE VIBRATION AND NOISE

Figure 3

models are correct. Then, the analyses can be validated using the data. This effort would make the tools available to analyze this problem, the engine-out transient performance problem, in the same kind of sophistication that we handle hover out-of-ground effects.

The rest of the aerodynamics needs can be broken down between fuel efficiency, which shows up in several advantages to the user, and increased speed. Of course, the configuration session got into speed. Here, we are really talking about advanced highspeed helicopters or the more conventional configuration. The program, as it was laid out, really seemed to address fuel efficiency in just about every way anyone could think of. In our discussions of this, no one had much to add. It's a good program, It was endorsed.

Speed is more than just performance. One of the reasons a helicopter doesn't go faster is that it then begins to shake or to make too much noise, or become hard to fly, or to produce loads in control systems; so if speed is going to be increased, it takes a systems approach - an interdisciplinary attack on speed. We had a lot of discussion about that in the course of our day. How does that relate to what NASA is doing? There were a couple of suggestions for things that might be different. One is that in model rotor wind tunnel testing, we should try to get more of the things we want to learn about in-flight behavior. It's desirable to measure vibration and measure noise - not just performance. The measurement in the tunnel of vibration, which properly indicates how an aircraft will shake, and the measurement in the tunnel of noise are both in their infancy, and can well get more attention. That would help us get more speed in a real sense.

Our second subsession was on acoustics and the NASA acoustics program addresses primarily the four bullets in Figure 4. The major objectives are to reduce rotor noise; develop a way to predict the noise (external noise), reduce interior (gearbox) noise, and finally, define what noise is - what is it that bothers people about noise.

There is a well laid out program that covers this across the board. In addition, NASA is currently responding to industry requests to put more attention on this area. They're in the process of coming up with an outline of a new initiative to broaden the current program. Hopefully, our critique here will help in planning that initiative. NASA is saying, "here's our program, but we hear you and we are going to expand it, or propose to expand it." We were really critiquing it before that expansion.

Now, what is the noise problem? We've attempted to summarize this in Figure 5. The noise problem is very complex because there are several sources of noise. These include the "conventional" noise of an airfoil going through the air as on an airplane, and noise of a periodic nature because the rotor is turning and comes by once per revolution, and added, complex sources because the blade runs into its own wake, or because it goes transonic at times on the advancing side. These all add up and what you hear is the sum total, but the analysis of each source is a little different. How you would measure each of those sources is also a little different, so that it is quite complex. Typically, researchers that are working on one piece of the problem, and have an enormous challenge, are not even addressing another part over on the other side of this chart.

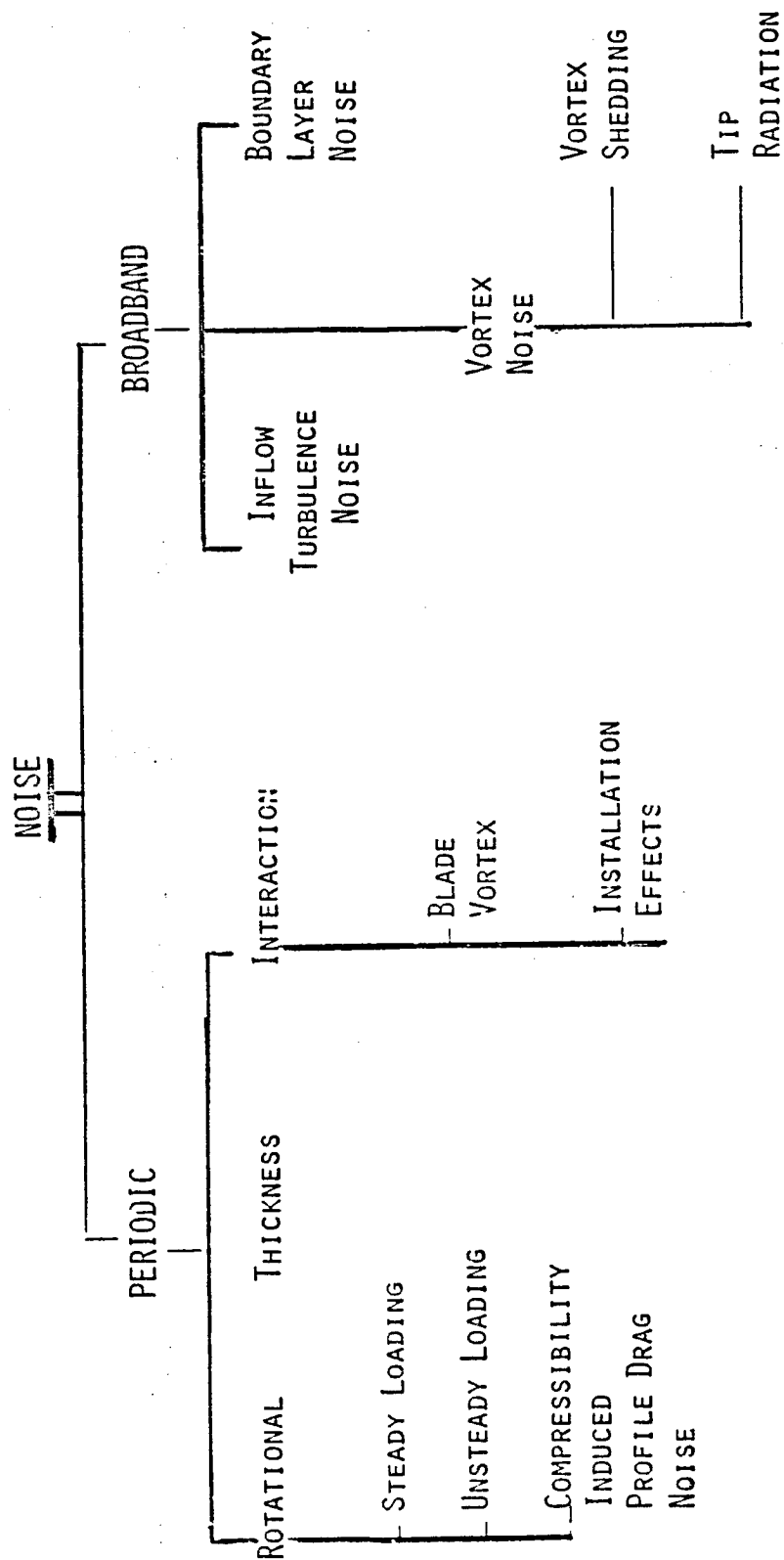
ROTORCRAFT ACOUSTICS

OBJECTIVES

- TO PROVIDE A TECHNOLOGY BASE FOR REDUCING ROTORCRAFT BLADE NOISE WITH MINIMUM PERFORMANCE PENALTY.
- TO DEVELOP AND VALIDATE AN ACCURATE METHODOLOGY OF ROTORCRAFT NOISE PREDICTION.
- TO DEVELOP THE TECHNOLOGY FOR REDUCING ROTORCRAFT INTERIOR NOISE LEVELS.
- TO QUANTIFY THE ANNOYANCE CHARACTERISTICS OF ROTORCRAFT NOISE.

Figure 4

ROTATING BLADE NOISE COMPONENTS



III-11

Figure 5

So, helicopter noise is a big problem with NASA's program, both here and at Langley, addressing just about all of it. It was pointed out several times, that trying to tie this all together to get the whole picture remains.

Internal noise is a part of the program. Most of the internal noise is generated by the transmission, and there are a number of ways to reduce that noise when generated or on its way from the transmission to the ears of the passengers. A four year plan working toward demonstrating ways to do this is underway at NASA - Langley.

Another unique facility here at Ames for measuring external noise is the Y03A. It is a super quiet airplane. You may have seen it flying around - I doubt if you've heard it flying around. It carries microphones on the tail. The helicopter whose noise is being measured, flies in formation with it, away from any obstructions, so that you then get free air noise measurements in a very nicely controlled environment. Quite a unique facility; and by shaping their formation differently, they can measure the noise in a different azimuth relative to the helicopter - to the source.

Our critique is summarized in Figure 6. The first need is low external noise - a number of the users asked for it. What does this mean? It has a number of elements to it. Right now, there's a great debate going on about noise regulations. FAA is in the process of adopting a rule which helicopters must meet. At the same time we're meeting here, the manufacturers are gathering in Washington to put together their rationale on why the rules should be different, or delayed. Fortunately, we didn't get into that debate in the course of our meeting yesterday - probably because everybody knew there was enough debate already taking place.

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA AERO-STRUCT.

SUB-AREA ACOUSTICS

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
LOW EXTERNAL NOISE	<ul style="list-style-type: none"> • MEET NOISE RULES 	LITTLE ACTIVITY	CONTINUE TIP IMPROVEMENT; MINIMIZE PENALTY OF LOW TIP SPEEDS.
	<ul style="list-style-type: none"> • DEFINE NOISE SOURCES • PROVIDE A DESIGN FOR NOISE CAPABILITY • QUANTIFY NOISE AVOIDANCE 	<p>ANALYSIS IN WORK</p> <p>IN WORK. VERY LONG TERM.</p> <p>IN WORK.</p>	<p>UPGRADE WIND TUNNEL AND FLIGHT EVALUATION TECHNIQUES INCLUDING 40 X 80' TUNNEL.</p> <p>CONSIDER SEMI-EMPIRICAL INTERIM METHODOLOGY.</p> <p>EMPHASIS NEEDED FOR PROPER DESCRIPTOR.</p>
LOW INTERNAL NOISE	<ul style="list-style-type: none"> • CRITERIA • NOISE REDUCTION MEANS 	<p>IN WORK</p> <p>LITTLE NASA EFFORT</p> <p>Figure 6</p>	CONTINUE PSYCHO-ACOUSTIC EFFORT. STUDY MEANS TO INTERRUPT STRUCTURAL PATH.

To meet the proposed new noise rules, things like improved tips and other ways of reducing rotor noise are recognized as a way to go. There isn't a lot in the NASA program at this point. Much of that tends to be configuration specific, and maybe there shouldn't be a lot in the NASA program. We will reach a point where all the tricks run out and fancy tips won't reduce the noise any more. The only way to go beyond that point is to slow the rotor down, if more reductions are needed to meet the rule. Then there is another research area that will open up. How do you slow the rotor down and not penalize yourself badly in performance or weight? Perhaps high lift airfoils will become more important, and we'll need more NASA involvement in that area. Much depends on where the rule comes to rest and how far we can tweak things like tips to get within the rule. Nobody really knows that answer yet.

Defining noise sources is a huge subject. Part of our problem in understanding where we are right now is the problem of good repeatable data in flight. We'd love to be able to do more of that in the wind tunnel, and this came up for some discussion and needs an emphasis. It's a shame to have to wait until you fly to find out where you stand on noise. In the process of all the work going on in the 40' x 80' wind tunnel expansion and improvement, we should be sure it is upgraded also to be a good noise measurement facility. Perhaps it even makes sense to model the way that tunnel would be treated in some smaller tunnel and make sure it's going to work so when that tunnel comes back up, we have a way to measure rotor noise without going out and flying it.

Even when you go out and fly to measure noise, it turns out not to be easy. If you run two tests on the same aircraft, or particularly, if two different agencies do it; they'll get two different answers. So, there's some technology of how you measure noise in a flight program that perhaps NASA can contribute to also.

A design-for-noise capability is very definitely in the NASA plan and that's what they're working on very hard. It's a long term job. Figure 8 showed all the sources and shows why the analysis is tough. One thing NASA might consider and one that the manufacturers had to fall back on in the meantime, is a semi-empirical way to get noise predictions. Maybe this can be left to the manufacturers - we're all doing it - or maybe NASA will see a way they can contribute to a more universal, semi-empirical noise predictor.

Finally, there's a requirement for quantifying the noise annoyance - psycho-acoustics - if you will. What is it that bothers people about helicopters? My next door neighbor has a power lawn mower. The kid across the street has a motorcycle. They make more noise than a lot of helicopters - at least in my living room they do. There's a suspicion that it isn't just helicopter noise that's of concern, but it's the fact that if you can hear something up there, maybe it's going to fall on you. For people who aren't in the aircraft business, that's an understandable concern. Maybe sometimes a noise complaint really is not about noise, it's about safety or something else. If the concern really isn't noise, it's more of a problem. If we really have to become undetectable so the public won't even know that a helicopter is overhead, then no amount of lowering the noise standards will do any good. This could be very important. I think one of the user's called it an "irrational response." If public noise demands remain irrational, we'll be frustrated in trying to meet that standard, so we need to get this down to numbers. In the case of both the aircraft requirement and the heliport requirement, we need to have noise descriptors that can be put down in technical terms that you can, in fact, meet. Then when some private citizen comes in and says that's too noisy, and what he really means is, he's afraid it will fall on his head, we can say no

it meets the standard that has been agreed to by all the world and it's OK. Hopefully, reason will prevail and the helicopter's potential won't be unnecessarily restricted.

There is another criteria question on internal noise. The question gets into the nature of the difference between the noise you hear in the helicopter and that which you hear in a fixed wing airplane or in other environments. How do you measure it, PNdB or speech interference levels or what? You get different numbers with different mixtures of kinds of noise, so we can't just say we'll meet fixed wing standards because of the different nature of the noise. Work is in process here. Noise reduction means are in the NASA program to some degree now - hopefully, we'll see it in their augmented program even further.

Let's go on to vibrations. I mentioned earlier that vibration reduction really turns out to be, in many cases, a means to accomplish reliability improvement. The NASA program (Figure 7) covers just about all elements of the problem: improving ways to predict the vibration sources, to predict better the airframe response, to suppress vibrations at the source, and to reduce response to residual vibration. It's a really good broad approach across the board. Three examples from that program are given here.

VIBRATION PROGRAM ELEMENTS

ROTOR LOADS ANALYSIS

AIRFRAME RESPONSE

ROTOR/AIRFRAME COUPLING



PREDICTION
METHOD

VIBRATION SUPPRESSION ROTOR

VIBRATION CONTROL METHODS

Figure 7

Every company is working on higher harmonic control and is delighted to see NASA supporting this to a real hardware demonstration. There are some things you just can't analyze.

So the user need in the vibration area isn't particularly low vibration. It is to get more speed, more payload, more reliability and keep the vibration down (Figure 8). We'd like to reduce the weight of the gadgets used to control vibration, to improve prediction capability, and then to have some concepts for working it cheaper and lighter.

One way of reducing the weight of vibration control, of course, is to build a rotor that doesn't create so much excitation in the first place. That is one of the objectives of the advanced rotor program that NASA is now pursuing - a major element of their program. If there was a message related to that that came out of our discussions, it was to be sure to keep as versatile as possible. Every manufacturer has his own pet idea of how you solve those problems, and the more versatile this methodology and hardware is, the better it will be able to try them all out.

Improved prediction capability is being addressed. I mentioned the NASTRAN before that's the big analytical problem we've all been working on for a long time. We're getting to the point where it should be possible to really have a correlated analysis of the loads and of the response of the airframe, so, we can say with some confidence, before you fly, what the vibration is going to be. One of the speakers at our session pointed out that the level of attention to vibration goes up dramatically after first flight, as though we didn't know we had to work on it before then. After the first flight we discover, "What do you know? It shakes!" We really have to get

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA AERO/STRUCT.

SUB-AREA VIBRATION

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
INCREASE - SPEED, PAYLOAD, R/M WITH LOW VIBRATION OF LATEST MODERN HELICOPTERS	<ul style="list-style-type: none"> REDUCE WEIGHT OF VIBRATION CONTROL IMPROVE PREDICTION CAPABILITY NEW CONCEPTS 	<p>ADV. ROTOR PROGRAM</p> <p>IN WORK</p> <p>IN WORK</p>	<p>ENDORSED - STRESS VERSATILITY TO HANDLE PASSIVE AND ACTIVE APPROACHES.</p> <p>PURSUAE AIRFRAME RESPONSE ANALYSIS TO SUCCESSFUL CORRELATION. <u>VALIDATE METHODS TO PREDICT ROTOR AND TAIL LOADS.</u></p> <p>SUPPORT HHC UNTIL FEASIBILITY IS CLEAR.</p>
INCREASED SPEED, R/M WITH LOW VIBRATION	<ul style="list-style-type: none"> EQUIPMENT FOR HELO ENVIRONMENT COMFORT CRITERIA 	<p>NO NASA PROGRAM</p> <p>SOME ACTIVITY UNDER ACOUSTICS PROGRAM</p>	<p>AUGMENT TO STUDY TOLERANT POWERPLANTS, SUITABLE EQUIPMENT SPECS.</p> <p>DEVELOP CRITERIA INCLUDING MULTIPLE HARMONICS AND NOISE.</p>

Figure 8

out of that mode. We're not in that mode because we haven't tried. It's a tough problem and NASA is working on it. Don't give up!

One relatively new element that got a lot of attention is loads coming in from the tail. We've all gone to high speed helicopters, and to make them fly better, we've put on bigger tail surfaces. More and more they then pick up the wake of the rotor, and we've all discovered that that's a pretty good source of excitation as well. So you can't just work the rotor as a source. The tail is another one, and work in that area is in the NASA plan.

I showed you the higher harmonic control in the OH-6. The message that came out of our discussion of that is "make sure you pursue it to the bottom line." It's been historic, unfortunately, that sometimes when you run one experiment it has a negative result even though it was a good idea to begin with. We hope the OH-6 test have a positive result, but should there be some kinds of difficulties, all the industry is watching this, so don't give up easily. NASA should press on until we find out whether HHC really has a fundamental problem or if fundamentally it will work, because we'd all like to use it.

Equipment for helicopter environment may have come up in the propulsion session as well. This gets back to the relationship between vibration and reliability. We think they are strongly related, but there is really little good quantitative correlation that anybody can point to. How much do you have to reduce vibration in order to get more reliability out of hardware? Are we already there, or how far do you go - what's the payoff? If some controlled experiments could define the vibration/reliability dependency for typical components, we could attack reliability improvement in a more rational way.

The NASTRAN finite element analysis of airframes has been used for years both for static stress prediction and for vibration prediction. In the vibration prediction area, it's been rather well recognized not to have been able to do the job. We get into heated debates as to whether the analysis or the analyst is the problem. If you take a "system" view of it, the system, the man plus the computer program, doesn't work well enough and needs to be improved. I guess nobody questions the mathematics. However, it's very tricky to load everything properly - to know how to represent the stiffnesses and masses and joints in an airframe so you can predict the vibration properly. It's a demanding problem. It's not like an airplane with a wing which has a couple of dominant modes. We may be worried about 30 modes of the airframe. The CH-53 program was run many years ago to try to correlate NASTRAN (with limited success). There is a new program now underway to review this and essentially do it again better and more carefully with the CH-47. That effort is just getting started.

Another area is the inter-action or coupling between the rotor and the airframe. It's now been learned you can't treat the rotor as a package and the airframe as a responding package and forget about the interaction one with the other, and so there are active programs NASA is supporting to find out how those two tie in together.

Thirdly, in the area of trying to suppress the vibration, a program now has been turned on to fly higher harmonic control. High frequency control inputs will be fed into the rotor, based on vibration seen in the airframe, to kill the vibration right at its source. Hughes is going to fly this on the OH6 and the whole industry is following it.

Perhaps we ought to write specifications differently for equipment to go on helicopters. Even prior to, and in addition to that, we would know how to target our vibration reduction efforts better. For example, we'd know that if you can drop from 0.2 g's to 0.1 g's in the avionics compartment, it will save so many millions of dollars in life cycle cost. If we had those numbers, we'd be better able to focus our efforts, to the user's benefit.

Comfort criteria come up in acoustics as well as vibrations. In the vibration area, this is a little complicated since a helicopter has more than one frequency of vibration in more than one direction, accompanied by noise. As we work this problem, how do you define goodness? What is the effect of frequency and of multiple frequencies? Are noise and vibration tolerances coupled or independent? Some basic work here would help us know how hard to work and in what direction.

Finally, the fourth area for our session was advanced composites. The NASA program here (Figure 9) is again broad. It includes flight service evaluation on aircraft, some basic research activities in composites applications, and then a new initiative looking towards the next generation of composite airframes which make more aggressive use of composites.

The flight program goes way back. The CH-54 has been flying for ten years with boron stiffeners. The S-76 is in service with advanced composites and the CH-53 cargo ramp is about to fly. The 206 composites program has just gone on contract. The S-76 stabilizer and tail rotor blades will be brought back from service after two, four, six, and eight years out flying in places like the Gulf. They will be tested in the laboratory, torn apart, cut up, bent, and broken to see what long term service does to advanced composites in the field.

NASA COMPOSITE HELICOPTER AIRFRAME PROGRAM

- FLIGHT SERVICE EVALUATION OF COMPONENTS
- ONGOING BASE RESEARCH ACTIVITIES
- PLANS FOR ADVANCED TECHNOLOGY DEVELOPMENT

Figure 9

In the Bell 206L program certain composite parts are being substituted for the normal parts, and put in service around the world. A large number of parts will be introduced and then brought back after they have had service exposure to see what the environment does to them. NASA aims to accelerate the learning process in both these cases to reduce the risk that hangs over this whole composites area as long as there is not as nearly as big a data base in the use of these materials as there is in metals.

Figure 10 indicates some of the people that NASA has been talking to about putting the parts on the 206. These actions are not all in firm plans yet, but you can see that the plan is going to put composite parts in a lot of places - a lot of different kinds of environments - and we should learn some things fairly quickly.

Figure 11 should clarify where the longer term NASA program fits to ACAP - the Army's Advanced Composite Airframe Program. ACAP is now in the heavy negotiation, competition stage. All of the contractors, who are here not talking about it are involved in competing for that program. What NASA has in mind, then, is the next step beyond ACAP, and it's not too early to begin thinking about that. What we're really recognizing is that we are on a very steep learning curve in use of composites at this point. Every time you try something new, you discover how you can do it even better next time. That steep learning curve is headed toward getting the full benefit of the composites. Until you have learned all you need to know, you tend not to push the strengths of these materials as far as you should and therefore not to get the benefits of weight saving and/or the reliability that is

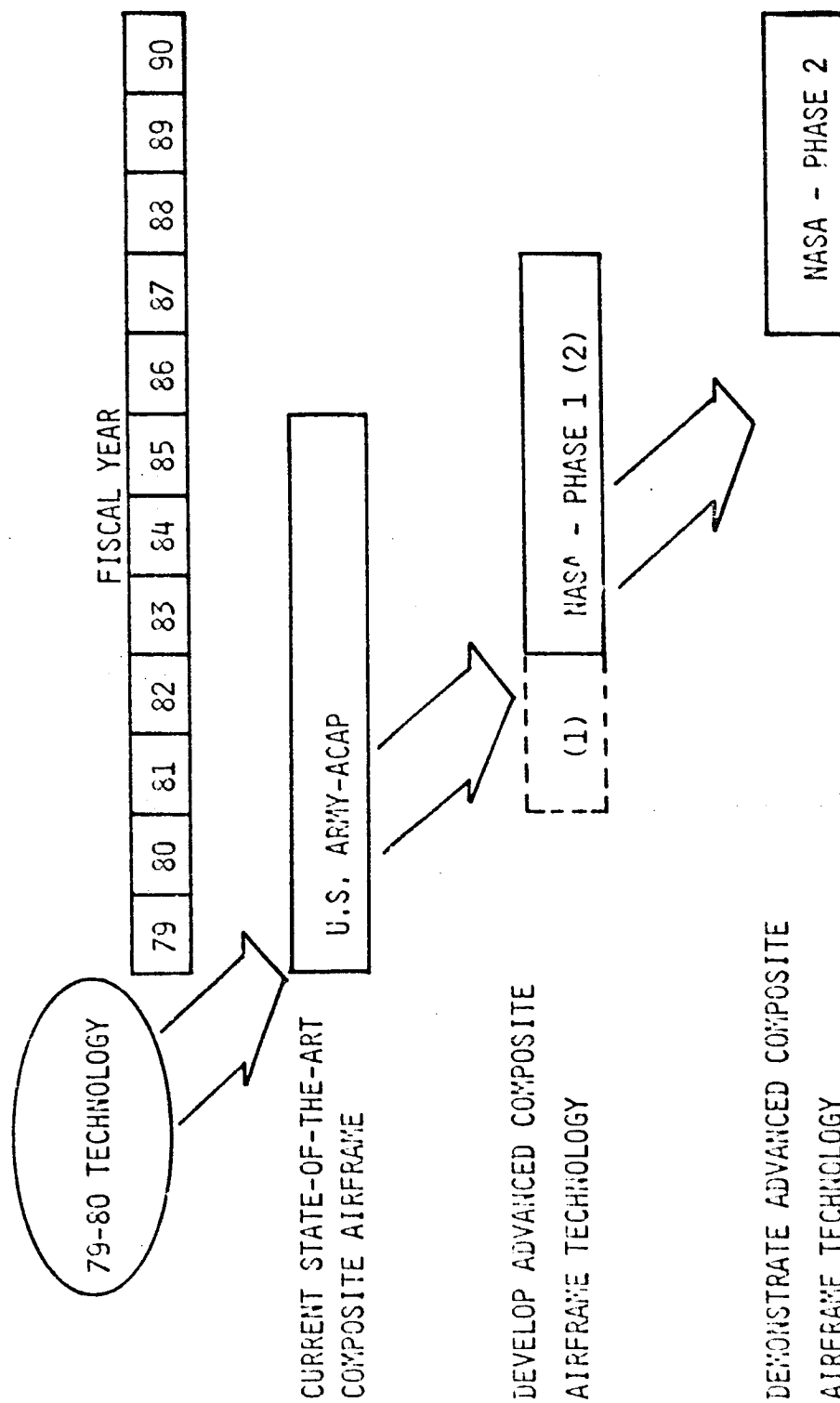
POTENTIAL OPERATORS TO EVALUATE COMPOSITE COMPONENTS

ON BELL 206L HELICOPTERS

<u>OPERATOR</u>	<u>LOCATION</u>
TRANSPORT CANADA	N.E. U.S./CANADA
HELI-VOYAGER	N.E. U.S./CANADA
HUISSON AVIATION LTD.	N.E. U.S./CANADA
ROYAL CANADIAN MTD. POLICE	N.E. U.S./CANADA
TRANS. QUEBEC LTD.	N.E. U.S./CANADA
TRANS. CANADA HELICOPTERS	N.E. U.S./CANADA
ROWSON AVIATION	N.E. U.S.
INTERPACE CORPORATION	NEW JERSEY
ISLAND HELICOPTER CORPORATION	NEWFOUNDLAND & LABRADOR
ERA HELICOPTERS, INC.	ALASKA
KENAI AIR ALASKA, INC.	ALASKA
MOBIL OIL CORPORATION	GULF COAST
BLEDSON AVIATION, INC.	GULF COAST
PETROLEUM HELICOPTERS, INC.	GULF COAST

Figure 10

COMPOSITE HELICOPTER AIRFRAME PROGRAMS



inherently there. So, this looks like a very timely step, rather loosely defined. What is it that the next generation will bring in that we don't have now? It is too early to say. If we knew what it was, we'd probably be putting it in now.

In summary, advanced composites address several user needs as shown in Figure 12 but I couldn't establish a one-to-one correspondence from user need. The user will get several benefits. Weight, cost and reliability are the primary reasons for advanced composites. Fuel economy comes from the reduced weight. A separate item, getting rid of corrosion, is an obvious benefit. More about crashworthiness in a moment. The first generation advanced composites are in evaluation right now, and the program covers it well. We're looking towards the next generation, towards really getting the best out of what composites have to offer. We essentially endorse their program in these areas - more application to primary structures, not just secondary.

More of a look at energy absorption - crashworthiness is needed. These materials tend to be brittle and if you don't design properly, you could wind up with something that is not crashworthy. It's a potential negative. We now know enough to know that if you design properly, you can turn that around and it's not a negative necessarily. Let's make it a positive.

Lower costs are not automatic. There are ways to build things of composites such that you don't, in fact, save money. Here, too, there's a learning curve, and the second generation of ACAP will provide even more payoff. The area of fatigue will need even more work and that was the one spiked out in our discussions. That will be getting more attention as we begin to push the materials closer to their full capability.

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA AERO/STRUCT.

SUB-AREA COMPOSITES

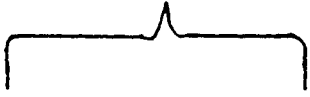
USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
<div>  <ul style="list-style-type: none"> REDUCED WEIGHT LOWER COST RELIABILITY FUEL ECONOMY NO CORROSION CRASHWORTHINESS </div>	ADVANCED COMPOSITES	FIRST GENERATION IN EVALUATION	ENDORSE FY '83 NEW INITIATIVES - <ul style="list-style-type: none"> • PRIMARY STRUCTURE • ENERGY ABSORPTION • LOWER COST • GREATER WEIGHT SAVING ALSO: IMPROVE STATIC AND FATIGUE ANALYSIS AND UNDERSTANDING OF FAILURE MODES TO MAXIMIZE POTENTIAL OF COMPOSITES.
LOW INTERNAL NOISE	ASSESSMENT OF BONDED STRUCTURE	EFFECTS ALMOST UNKNOWN	EVALUATE EFFECT OF BONDED STRUCTURE AND OF COMPOSITE PROPERTIES ON NOISE.

Figure 12

And finally, we noted one other side effect of composites. If you bond the whole airframe, it tends to be a nice tight structure without any little slip of joints where there are rivets and that sort of thing. There is some concern that the inside of the cabin is going to be like the inside of a drum. Transmission noise may be transmitted better and make cabin noise a good deal worse than it is with a metal airframe with all of its imperfections. Really, at this point, it isn't known whether that's going to be a bigger problem or a lesser problem. There have been some tests that say it's not quite as bad as I've made it sound. Here again though, there is an opportunity to turn composites into a plus and not a minus. Composites can be tailored to do many things, and there ought to be ways to make the composite structure not only strong and light, but capable of damping out those noises before they get down into the cabin. This may be long term, but it's an area where perhaps again NASA can help.

Generally, in our session, we tried to say what the user had told us he wanted and to respond to it. I must say that the users were generally not at our meetings. I hope we heard you right.

The NASA program in the Aerodynamics/Structures area is extensive, and could be given only a limited treatment in the time available. This summary has tended to emphasize the changes we'd like to see, but it needs to be said, again, that the current program is endorsed in most areas. As helicopter fleets and usage continue to grow, technology improvement still to be made can have a substantial pay-off, and we welcome and encourage NASA's participation with us in this exciting future.

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NASA ROTORCRAFT AERODYNAMICS PROGRAM

Wayne Johnson

There are two primary objectives of NASA's research program on helicopter aerodynamics and performance. The first objective is to develop improved aerodynamic design methodology for helicopters and rotors, thereby reducing the engineering development required for new or improved rotorcraft designs. The end result is reduced aircraft development costs. The second objective is to develop rotors and rotorcraft with improved aerodynamic efficiency, thereby reducing aircraft operating costs. Alternatively, improved efficiency can be used to offset performance degradations due to other design constraints (such as noise). The approach for this research program involves both in-house and contracted work. The approach consists of theoretical investigations, including analysis technique developments and the development of design or evaluation computer programs; small scale wind tunnel investigations, including tunnels for airfoils, low speed tunnels, and transonic tunnels, both in government and in industry; full scale wind tunnel investigations, conducted in the 40- by 80ft/90- by 120-ft Wind Tunnel; and flight investigations on both government and industry research helicopter, and on the Rotor Systems Research Aircraft (PSRA). The aerodynamics program may be divided into five major research areas: 2D and 3D aerodynamic phenomena; aerodynamic phenomena of the rotating blade; rotor aerodynamic performance and loads; fuselage aerodynamics; and rotorcraft aerodynamics.

2D and 3D aerodynamic phenomena are those problems of helicopter rotors that can be modelled by nonrotating flows, perhaps even two-dimensional flows. Specific problems are dynamic stall; blade-vortex interaction; tip vortex formation, including the influence of tip shape and the design of optimal tip geometries; airfoil sections; and the transonic flow over blade tips. These phenomena can be related to the principal problems of helicopter rotors: adverse effects on performance, high loads, high vibration, high noise, and adverse effects on handling qualities. For example, dynamic stall is a factor in loads, vibration, and handling qualities limitations; and the blade tip vortices are involved in almost all of the problems of the helicopter.

Aerodynamic phenomena of the rotating blade are those problems that inherently involve influences of rotation on the flow, and consequently also involve the entire rotor. Specific problems are the rotor wake, including its formation, structure, and influence on the blade airloads; and computational fluid dynamics, including development of transonic (3D, rotating, unsteady) and Navier-Stokes codes. Again these research areas can be related to the principal problems of helicopter rotors (although rotary wind phenomena are so complex and inter-related that it can also be argued that every specific phenomena influences to some extent all the problems).

Rotor aerodynamic performance and loads are those problems that involved the integrated effects of the aerodynamics on the helicopter rotor. Specific problems are rotor performance, including prediction or optimization, and the influence of tip planform and other variables; blade

airloads measurement and prediction; and investigations of advanced configurations, including full scale wind tunnel tests and flight tests on the RSRA.

Fuselage aerodynamics are those problems that involve the aerodynamics of the fuselage and tail. Specific problems are the drag of the helicopter fuselage and hub, which is a major factor in the aircraft performance; and the aerodynamics of the airframe and tail, which influence the helicopter handling qualities.

Rotorcraft aerodynamics are those problems that involve the entire helicopter, particularly interference effects. Specific problems are the interactional aerodynamic characteristics, both mean and vibratory interference; and the aerodynamic performance of the complete aircraft.

In summary, the aerodynamic research program of NASA included work on the entire spectrum of phenomena, from 2D nonrotating problems, to the aerodynamic of the entire helicopter. The research has the objective of developing improved understanding of the phenomena and the means to predict them, thus improving helicopter design methodology. The research is also directed at developing rotors and rotorcraft with better aerodynamic efficiency and expanded capability.

AERODYNAMICS

Major Tasks	Descriptions	Contacts (and RTOPs)
1. 2D and 3D Aerodynamic Phenomena	Investigations are being conducted of rotary wing aerodynamic problems that can be modelled by nonrotating, or even 2D flows. The objectives are to define the phenomena, develop means to predict the flows, and develop means to alleviate the adverse effects. The work involves theoretical and small scale wind tunnel investigations. Specific problems are dynamic stall; blade-vortex interaction; tip vortex formation, including the influence of tip shape and the design of optimal tip geometries; and airfoil sections.	G. Bingham, LaRC (505-42-23) A. Johnson, ARC (505-42-21) R. Presley, ARC (505-42-21) W. Young, LaRC (505-42-13)
2. Aerodynamic Phenomena of Rotating Blade	Investigations are being conducted of rotary wing aerodynamic problems that inherently involve influences of rotation on the flow, and involve the entire rotor. The work involves theoretical, small scale wind tunnel, and full scale wind tunnel investigations. Specific problems are the rotor wake, including its formation, structure, and influence on the blade airloads; and computational fluid dynamics, including development of transonic (3D, unsteady, rotating) and Navier-Stokes codes.	W. Johnson, ARC (505-42-21) R. Presley, ARC (505-42-21) V. Peterson, ARC W. Young, LaRC (505-42-13)
3. Rotor Aerodynamic Performance and Loads	Investigations are being conducted of the aerodynamic performance and airloading of helicopter rotors. The objectives are to define the aerodynamic phenomena, develop means to predict the performance and loads, and develop more efficient rotors. The work involves theoretical, small scale and full scale wind tunnel, and flight investigations. Specific activities involve rotor performance, including prediction or optimization, and the influence of tip planform and other variables; blade airloads measurement and prediction; and investigations of advanced configurations, including fullscale wind tunnel tests and flight tests on the RSRA.	J. Biggers, ARC (532-03-11) W. Johnson, ARC (505-42-21) 532-03-11 R. Presley, ARC (505-42-21) J. Wilson, LaRC (505-42-23)

4. Fuselage Aerodynamics

Investigations are being conducted of the aerodynamic problems of helicopter fuselage and tail. The work involves theoretical, small scale wind tunnel, and full scale wind tunnel investigations. Specific problems are fuselage drag, hub drag, and tail aerodynamics.

W. Johnson, ARC (505-42-21,
532-03-11)
R. Presley, ARC (505-42-21)
J. Wilson, LARC (505-42-23,

5. Rotorcraft Aerodynamics

Investigations are being conducted on aerodynamic phenomena of entire helicopter, particularly interference effects. The work involves theoretical, small scale and full scale wind tunnel, and flight investigations. Specific concerns are the interactional aerodynamic characteristics, both mean and vibratory interference; and the aerodynamic performance of the complete aircraft.

J. Biggers, ARC (532-03-11)
W. Johnson, ARC (505-42-21,
532-03-11)
R. Presley, ARC (505-42-21)
J. Wilson, LARC (505-42-23)

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NASA ROTORCRAFT AERODYNAMICS PROGRAM

OBJECTIVES

DEVELOP IMPROVED AERODYNAMIC DESIGN METHODOLOGY FOR HELICOPTERS AND ROTORS

THEREBY REDUCING ENGINEERING DEVELOPMENT REQUIRED FOR NEW
OR IMPROVED ROTORCRAFT DESIGN

HENCE REDUCING AIRCRAFT DEVELOPMENT COSTS

DEVELOP ROTORS AND ROTORCRAFT WITH IMPROVED AERODYNAMIC EFFICIENCY

THEREBY REDUCING AIRCRAFT OPERATING COSTS

OR OFFSETTING PERFORMANCE DEGRADATIONS DUE TO OTHER DESIGN
CONSTRAINTS (SUCH AS NOISE)

APPROACH

THEORETICAL INVESTIGATIONS

ANALYSIS TECHNIQUE DEVELOPMENTS

DESIGN AND EVALUATION CODES

SMALL SCALE WIND TUNNEL INVESTIGATIONS

SMALL TUNNELS (AIRFOILS)

LOW SPEED TUNNELS

TRANSONIC TUNNELS

FULL SCALE WIND TUNNEL INVESTIGATIONS

40X80/80X120-FOOT WIND TUNNEL

FLIGHT INVESTIGATIONS

RESEARCH HELICOPTERS

RSRA

IN-HOUSE AND CONTRACTED WORK

ROTORCRAFT AERODYNAMICS PROGRAM

MAJOR TASKS

2D AND 3D AERODYNAMIC PHENOMENA

AERODYNAMIC PHENOMENA OF ROTATING BLADE

ROTOR AERODYNAMIC PERFORMANCE AND LOADS

FUSELAGE AERODYNAMICS

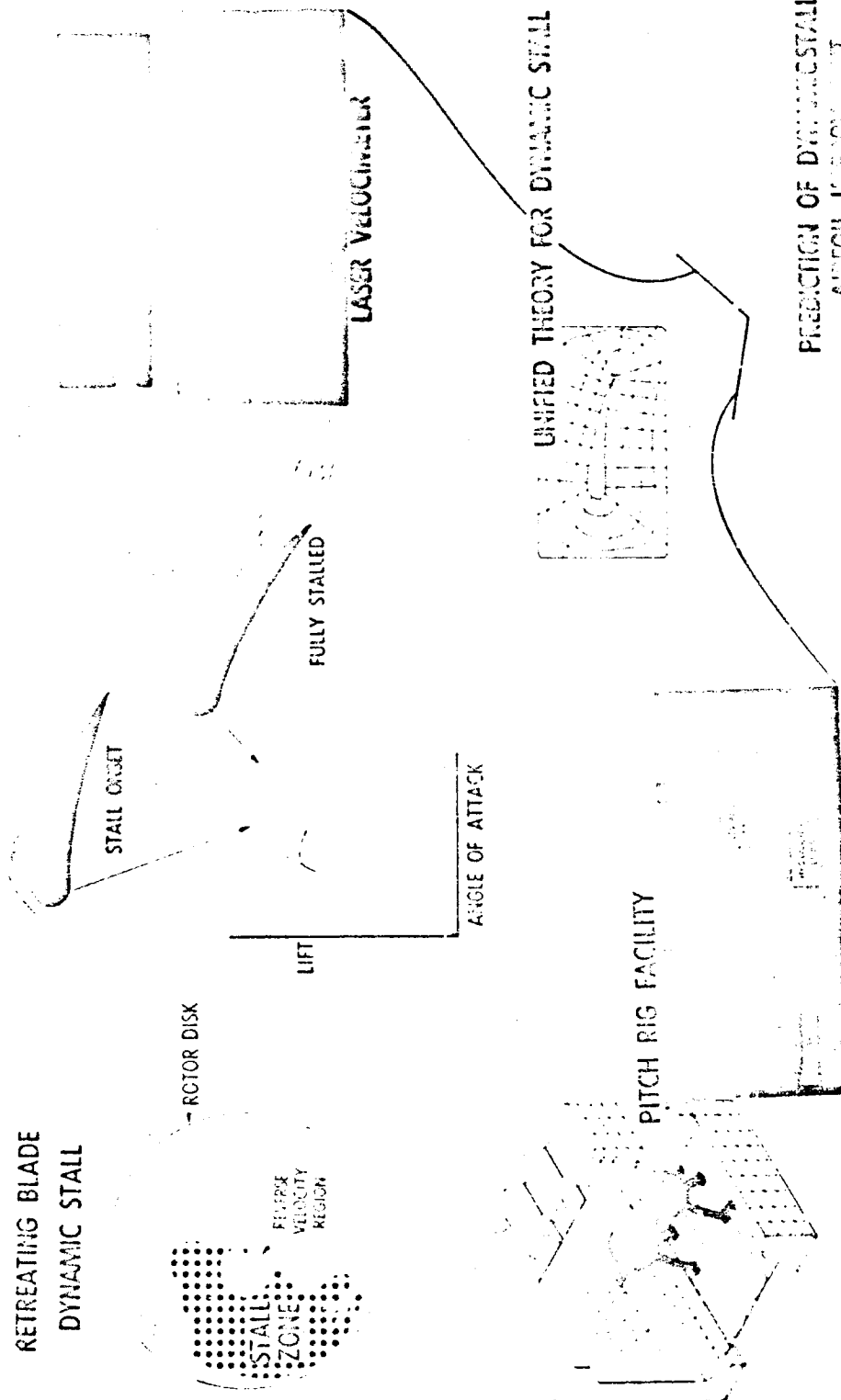
ROTORCRAFT AERODYNAMICS

2D AND 3D AERODYNAMIC PHENOMENA

<u>SUBJECTS</u>	PERFORMANCE	LOADS	VIBRATION	NOISE	HAND. QUAL.
DYNAMIC STALL		X	X		X
BLADE-VORTEX INTERACTION		X	X	X	
TIP VORTEX FORMATION	X	X	X	X	
AIRFOILS	X				
TRANSONIC TIPS	X	X	X	X	

UNSTEADY AERODYNAMICS

RETREATING BLADE
DYNAMIC STALL



Components of dynamic stall research.

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TIP SHAPE FORMATION

PRESSURE MEASUREMENT EXPERIMENTS

PREVIOUS WORK

NOISE REDUCTION

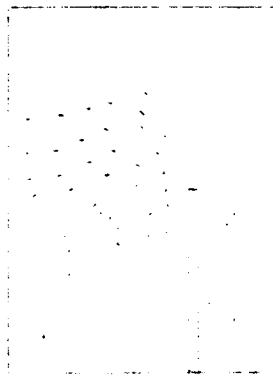


NOISE REDUCTION
PERFORMANCE CONTROL



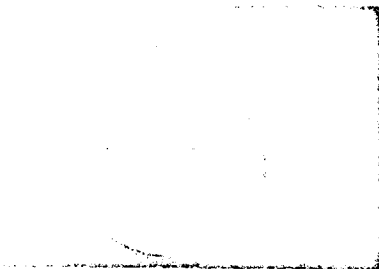
DFVLR TESTS

THEORETICAL ANALYSES



HAVIER-STOKES

INVISID



HOVER TEST

GOALS

OPTIMIZED TIP SHAPE

MISSION TAILORED PERFORMANCE

ANALYTICAL INPUTS TO
ROTOR WAKE CALCULATIONS

AERODYNAMIC PHENOMENA OF ROTATING BLADE

HAND, QUAL.

NOISE

VIBRATION

LOADS

PERFORMANCE

SUBJECTS

X

X

X

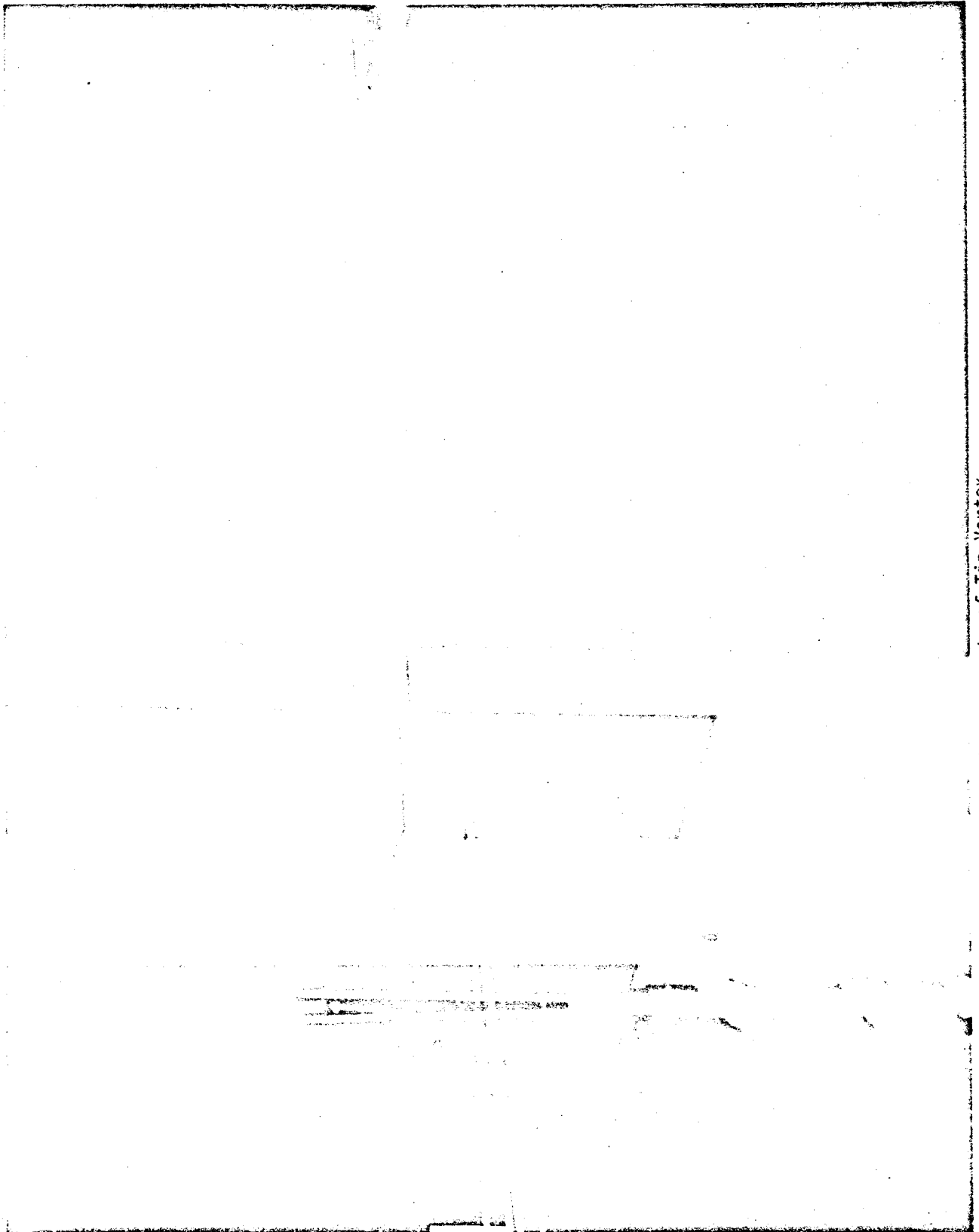
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POTOR MAKE

X

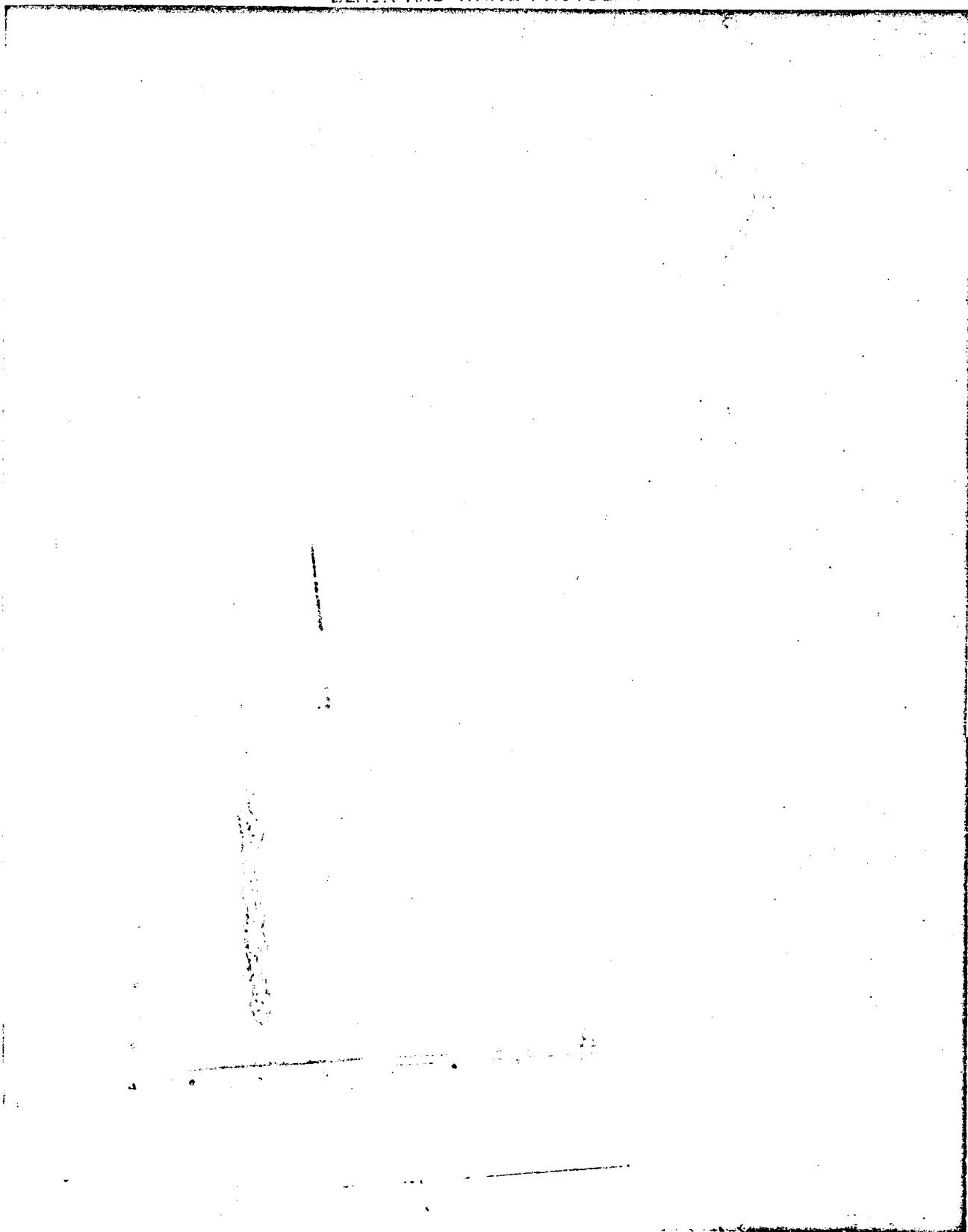
COMPUTATIONAL FLUID DYNAMICS

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LV Measurements of Tip Vortex

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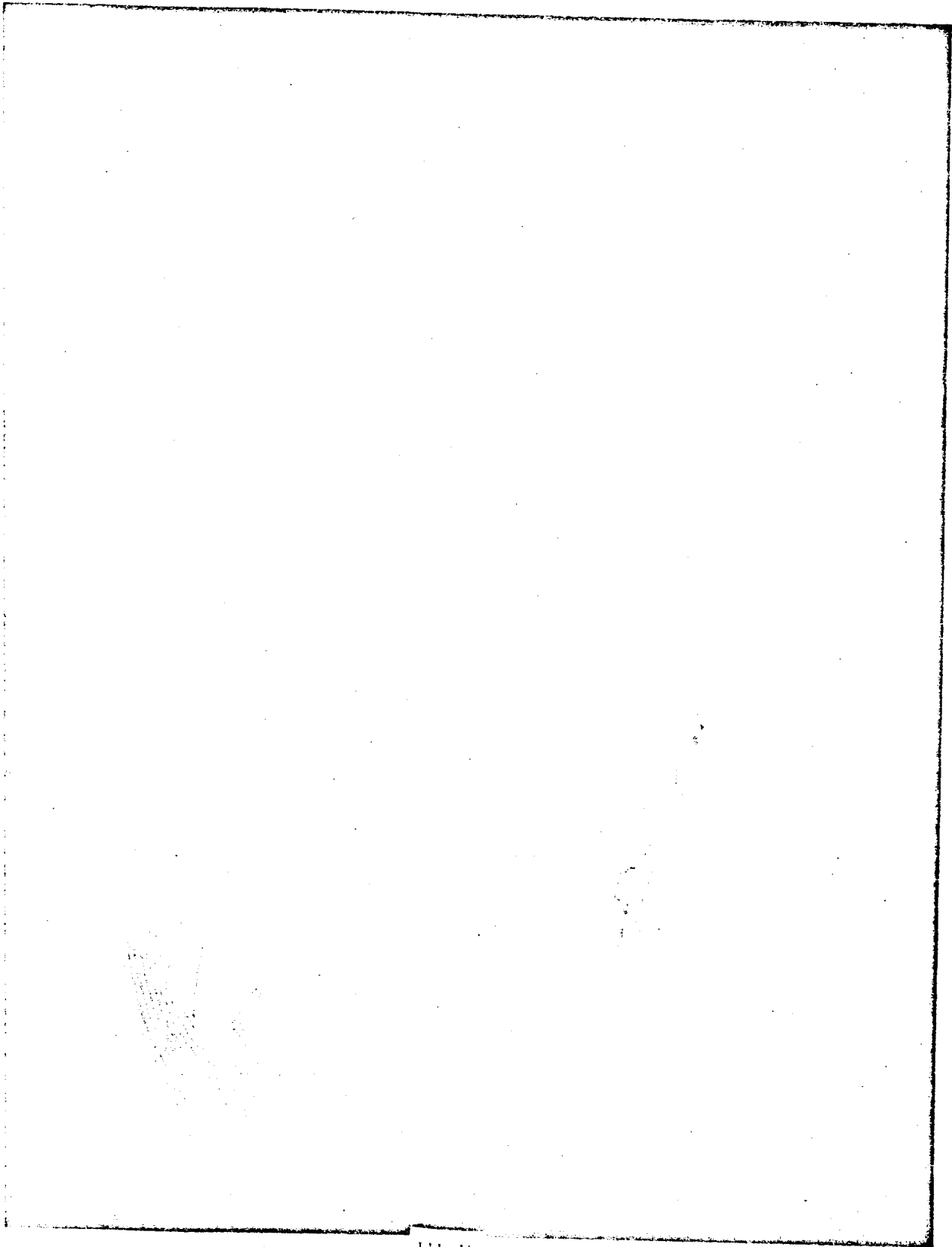
LV Measurements of Wake

III-43

ROTOR AERODYNAMIC PERFORMANCE AND LOADS

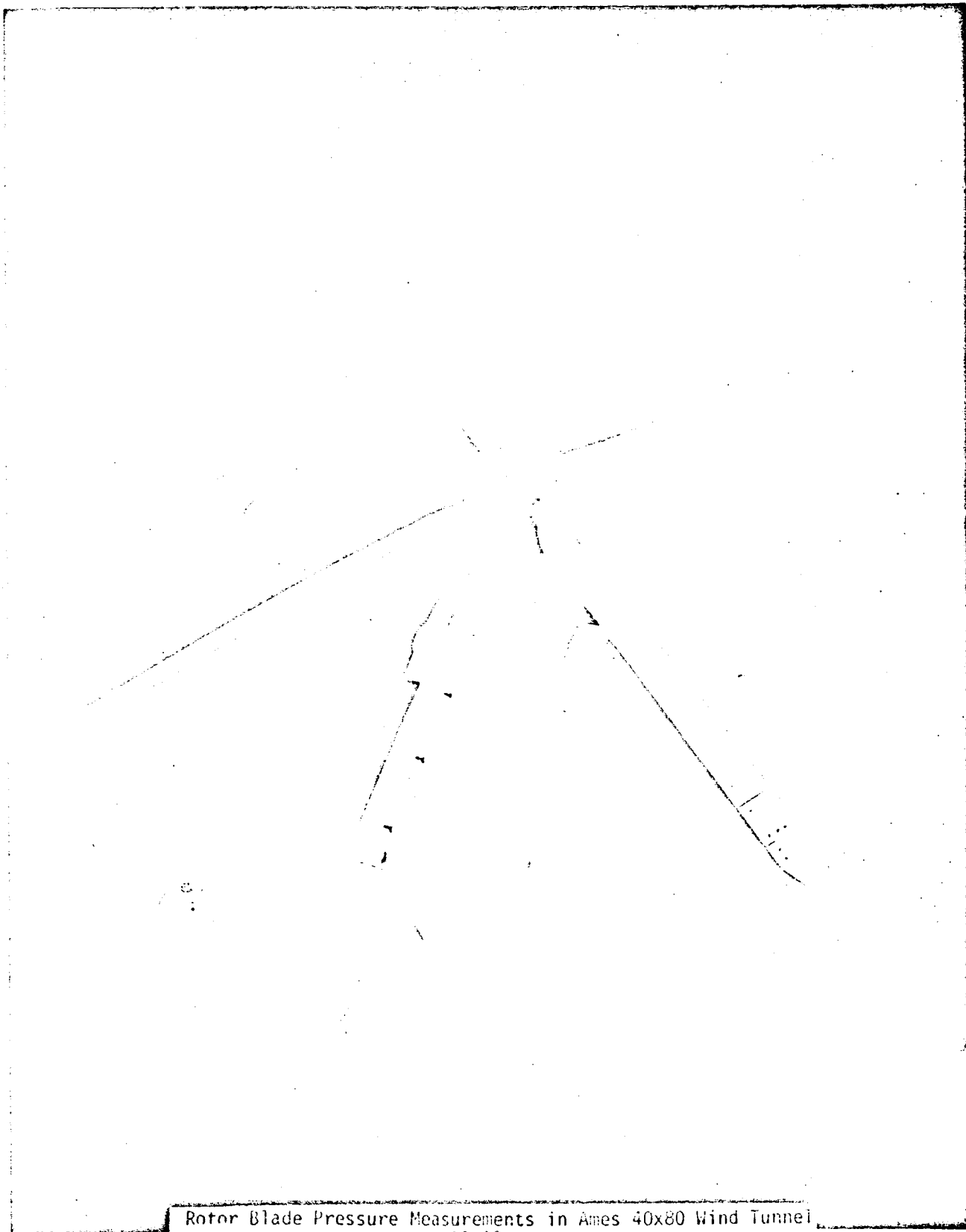
<u>SUBJECTS</u>	PERFORMANCE	LOADS	VIBRATION	NOISE	HAND. QUAL.
ROTOR PERFORMANCE	X				
BLADE AIRLOADS		X	X	X	
ADVANCED CONFIGURATIONS	X				

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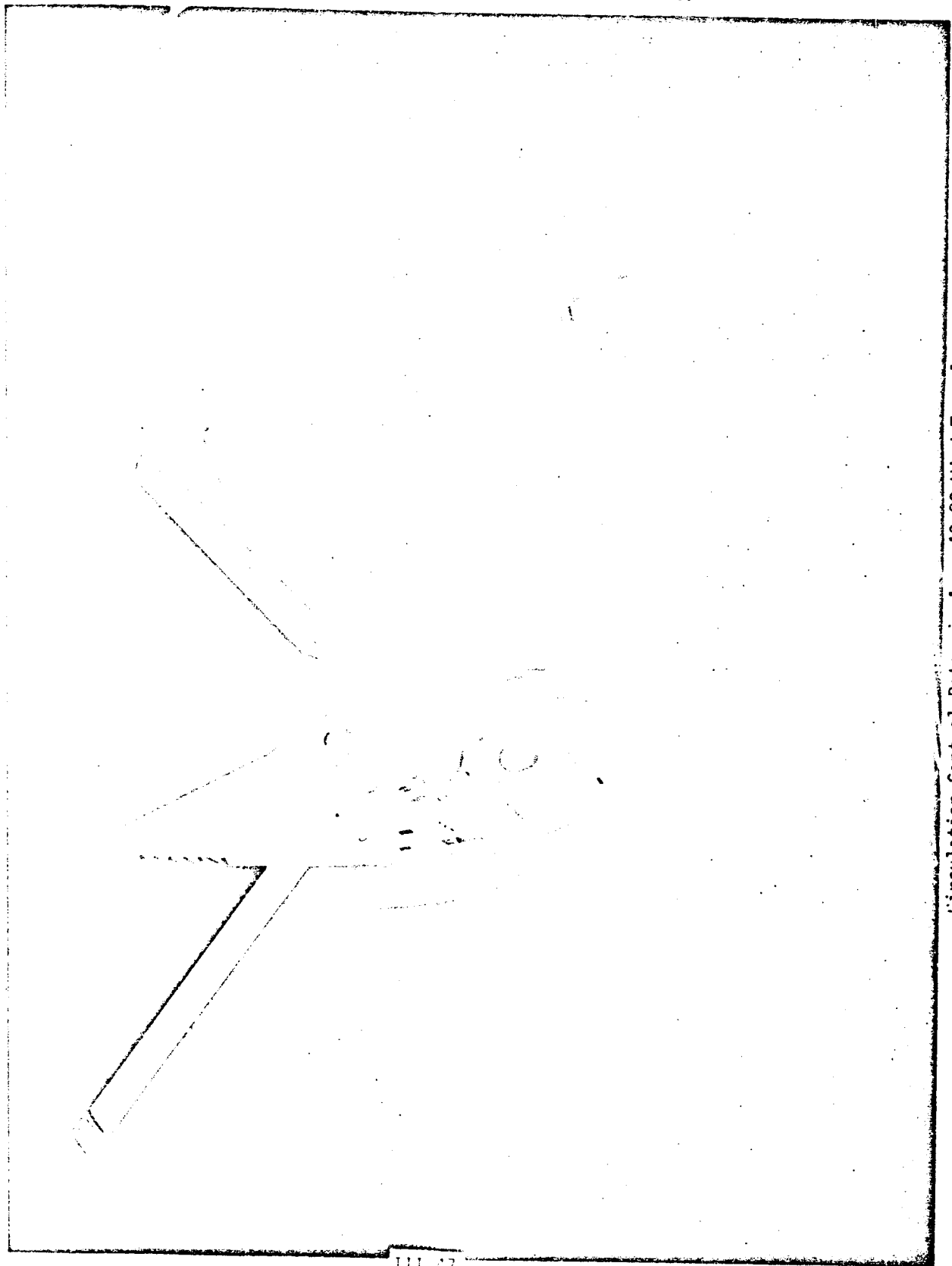
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Rotor Blade Pressure Measurements in Ames 40x80 Wind Tunnel
111-46

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Circulation Control Rotor in Ames 40x80 Wind Tunnel

FUSELAGE AERODYNAMICS

PERFORMANCE
LOADS
VIBRATION
NOISE
HAND. QUAL.

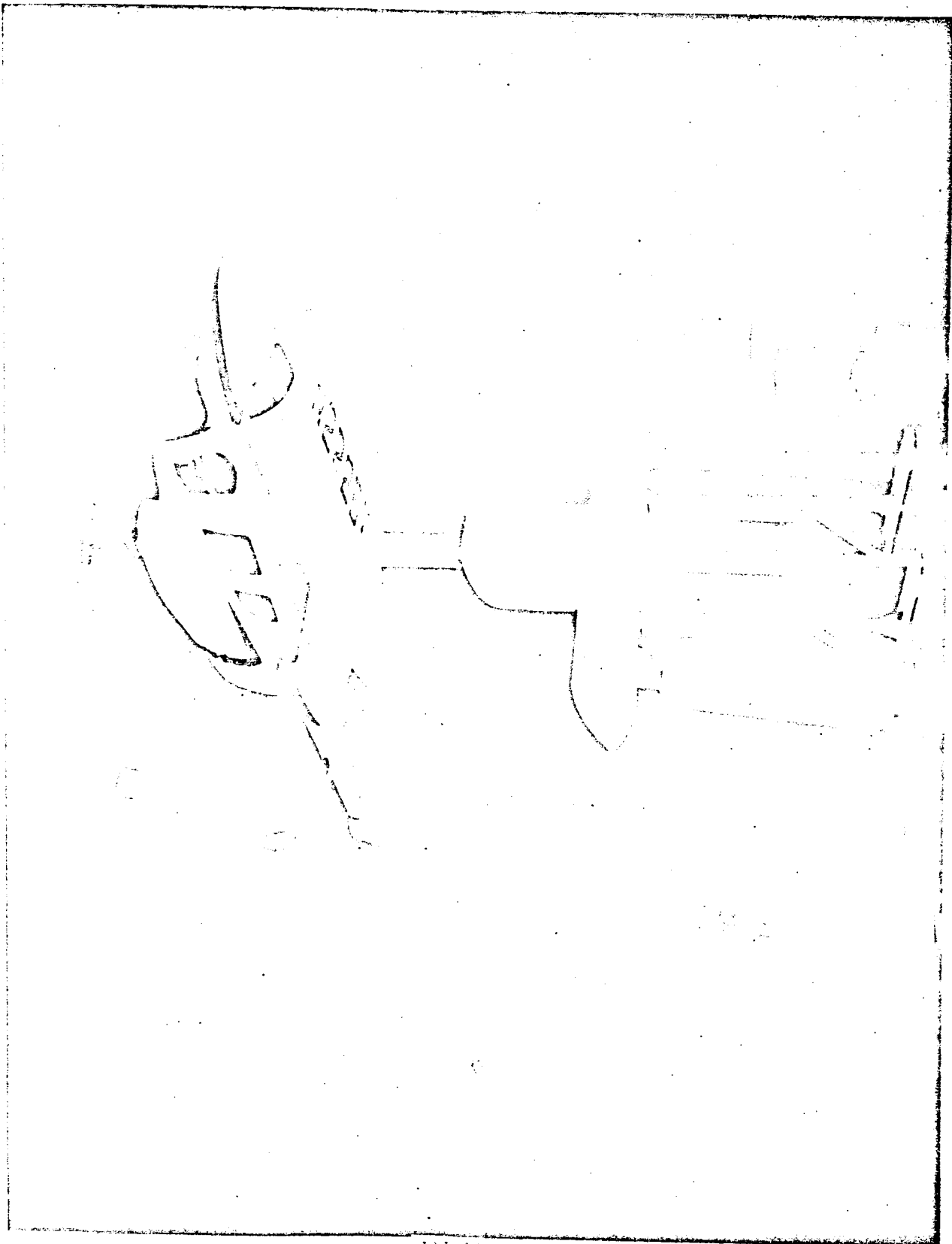
SUBJECT

FUSELAGE AND HUB DRAG
FUSELAGE AND TAIL AERO.

X

X

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ROTORCRAFT AERODYNAMICS

SUBJECT

INTERACTIONAL AERODYNAMICS

COMPLETE AIRCRAFT

PERFORMANCE

X

✕

LOADS

X

VIBRATION

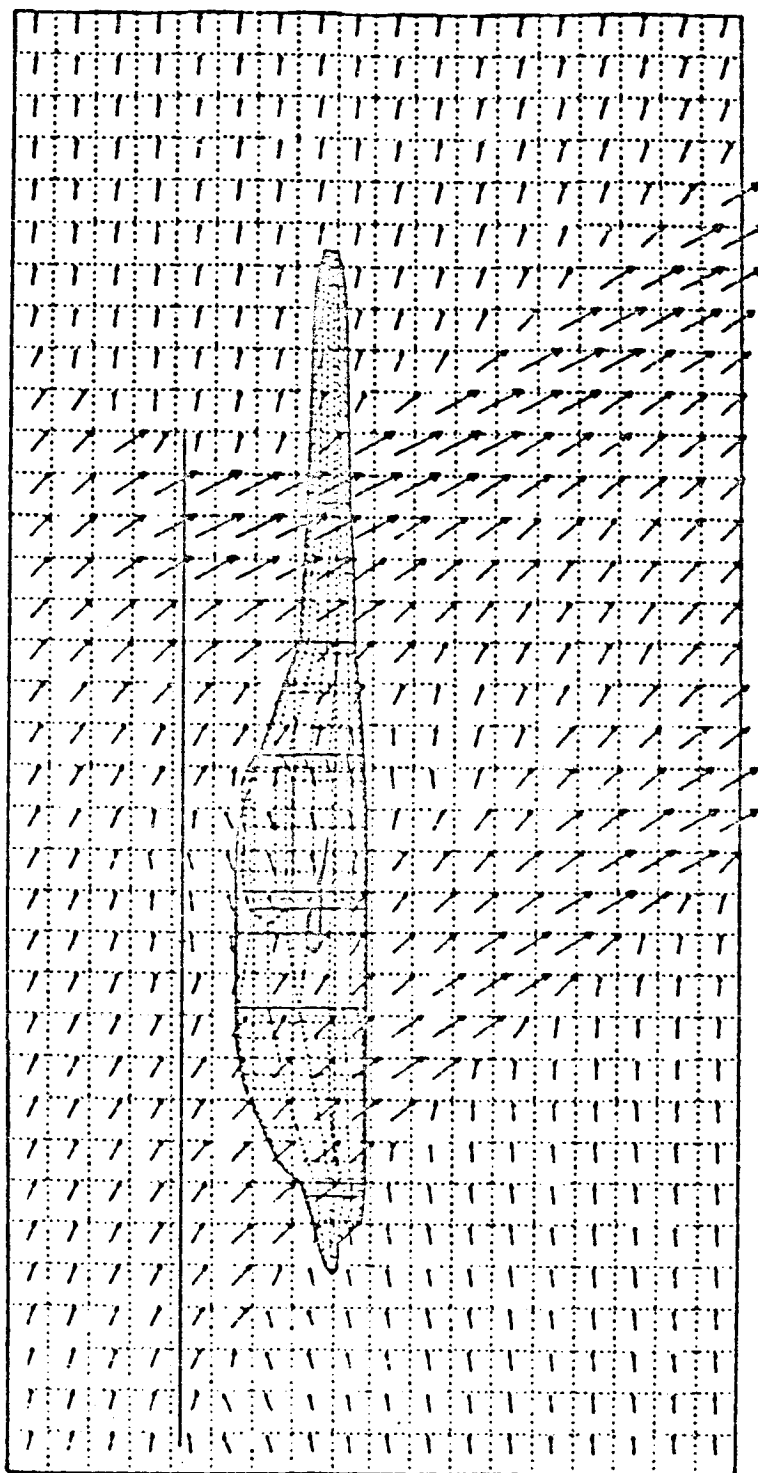
X

NOISE

HAND, QUAL.

X

FLOW FIELD WITH ROTOR AND FUSELAGE REPRESENTATION



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Rotor Systems Research Aircraft

NASA ROTORCRAFT RESEARCH PROGRAM

AERODYNAMICS AND PERFORMANCE

ENTIRE SPECTRUM OF AERODYNAMIC PHENOMENA, FROM 2D NONROTATING TO COMPLETE HELICOPTER

DEVELOPING IMPROVED UNDERSTANDING OF PHENOMENA AND MEANS TO PREDICT THEM, THUS
IMPROVING HELICOPTER DESIGN METHODOLOGY

DEVELOPING ROTORS AND ROTORCRAFT WITH BETTER AERODYNAMIC EFFICIENCY AND EXPANDED
CAPABILITY

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OVERVIEW OF NASA'S ROTORCRAFT ACOUSTICS PROGRAM

J. P. Raney, D. R. Hoad, and J. C. Biggers

INTRODUCTION

The purpose of this presentation is to outline the essential elements of NASA's present rotorcraft acoustics program. Participating in this research activity are the Langley, Ames, and Lewis Research Centers. Overall program direction is provided by Mr. John Ward, NASA Headquarters, Washington, D. C.

OBJECTIVES

NASA's goal is to develop technology leading to noise reduction and to accurate prediction methodology - that is, a design-for-noise capability. Additional goals include the reduction of interior noise and the quantification of the annoyance characteristics of rotorcraft noise.

Our objectives may be enumerated as follows:

1. To provide a technology base for reducing rotorcraft blade noise.
2. To develop and validate accurate methodologies of rotorcraft aerodynamic and noise prediction.
3. To develop the technology for reducing rotorcraft interior noise levels.
4. To develop improved noise metrics for quantifying the annoyance characteristics of rotorcraft noise.

PROGRAM MILESTONES

Our program may be described in terms of its major tasks, anticipated milestones, and expected results as indicated in figures 1 and 2. The

remainder of this presentation deals with a discussion of these milestones and their significance in achieving the expected results shown in figures 1 and 2.

ADVANCED NOISE PREDICTION METHODOLOGY

As indicated in figure 3, the emphasis of this task is on developing and validating a comprehensive design-for-noise capability for rotorcraft. The Langley Research Center provides the focus for this activity.

Figure 4 shows a typical result of a recent prediction validation study in which Bolt Beranek and Newman exercised the Farassat/Nystrom rotor noise prediction program (ref. 1) to compare predicted noise levels with an existing aeroacoustic data base (the so-called Bell Operational Loads Survey data base) of measured blade pressure loads and far field (ground) noise levels.* The calculated results were made using the Bell measured blade pressures and assumed a hard ground plane. Noise levels in the forward arc are slightly under predicted; however, the rear arc levels are overpredicted by as much as 3 dB.

Figure 5 shows a comparison of measured and calculated harmonics for an emission angle of 15 degrees (forward arc - aircraft approaching). The first several harmonics are underpredicted which results in the forward arc under-predictions shown in figure 4.

The results of this study and a similar study using Sikorsky CH-53 data (ref. 2) are encouraging and indicate good agreement between measured and calculated noise levels dominated by thickness effects and deterministic periodic blade loading.

*To be published as a NASA Contractor Report in 1981.

Figures 6 and 7 give further prediction validation results. In figure 6 the predicted sound pressure pulse (thickness effects only) for a scale model UH-1D helicopter with standard existing blades is in nearly perfect agreement with the measured pulse.

In figure 7, the same time pulse is shown on the right. In the top left portion of the figure is a calculation of the noise reduction potential in terms of SPL of the advanced blade design using the Farassat/Nystrom prediction program. In the bottom left of the figure the calculated noise reduction in terms of peak-to-peak sound pressure is shown to be in excellent agreement with the experimental results.

The results shown in figures 6 and 7 are particularly noteworthy because the advanced model rotor was designed for improved aerodynamic efficiency. Not only was the aerodynamic efficiency increased compared to the original design blades but the overall noise was reduced by 10 dB. These results are clearly indicative of the benefits to be obtained from the application of advanced noise prediction and aerodynamic optimization methodologies in which rotorcraft performance and noise tradeoff studies can be confidently conducted. The addition of broadband and nonlinear effects to the Farassat/Nystrom program (as shown in figure 1) will further enhance the usefulness of NASA's advanced prediction capability.

BASIC NOISE RESEARCH

The second task area is basic noise research which attempts to isolate and quantify fundamental noise generating mechanisms. The effect of tip shape on blade/vortex interaction (BVI) has been studied and reported in reference 3. Figure 8 shows a comparison of the noise levels of five tip shapes tested

which indicates that proper selection of tip shape can reduce BVI by altering critical vortex characteristics. The BVI phenomenon is the focus of continuing research on basic mechanisms and the effects of scale.

Another major area of basic noise research is nonimpulsive or broadband noise. Figure 9 indicates several of the potential noise generating mechanisms associated with broadband noise. An experiment in Langley's anechoic flow facility will be conducted in the near future in which these mechanisms will be isolated and studied individually with the goal of achieving a quantitative ranking of the importance of each. Figure 10 summarizes Langley's current nonimpulsive research activity.

MODEL SCALE AEROACOUSTIC DATA BASE

The model-scale and full-scale data acquisition tasks are described in figure 11. Figures 6 and 7 showing tunnel data for the UH-1D model, highlighting prediction validation research, provide a good example of the applicability to validation of model-scale acoustic data obtained from the Langley V/STOL tunnel. Figures 12, 13, and 14 show an RSRA model, an AH-1G model, and the UH-1D model respectively in the V/STOL tunnel. These figures indicate the evolving application of the V/STOL tunnel to acoustic measurements. Using an early RSRA model, BVI was generated and measured. No acoustic treatment was used. The AH-1G model was used again to generate and measure BVI for comparison with full-scale data for this mechanism. Acoustic treatment was used to enhance the quality of the measurements. Finally, figure 14 shows the UH-1D model previously discussed together with further improved acoustic treatment.

The V/STOL tunnel is presently capable of generating high quality acoustic data. Further enhancements will continue to improve upon this capability. The V/STOL tunnel will play an integral role in NASA's rotorcraft acoustics program.

FULL SCALE AEROACOUSTIC DATA BASE

The acquisition of full-scale aeroacoustic data is an essential element in validating prediction methodology and in quantifying the effects of scale on aeroacoustic data. Current planning calls for acquisition of comprehensive air-to-air and air-to-ground data sets for the Cobra (AH-1G) at the Ames Research Center in the early spring of 1981. The YO-3 aircraft used to acquire the air-to-air data is shown with the Cobra in station keeping position in figure 15.

The test matrix for the Cobra flight experiment has been jointly prepared and agreed upon by the Ames and Langley Centers. The results of the flight experiment will be used to guide and correlate with a portion of the V/STOL Cobra experiment indicated in figure 1.

MODEL/FLIGHT SCALE ACOUSTIC CORRELATION

As indicated in figure 16 determination of the effects of scale on noise mechanisms is an important task in the rotorcraft acoustics program. The first efforts will involve the AH-1G and UH-1D aircraft model and flight aeroacoustic data sets as indicated in figure 1 and will focus on BVI. Figure 17 provides an example of an early attempt to correlate (mentioned earlier) the effects of scale on BVI for a model and full-scale AH-1G Cobra aircraft. Notice the similarities between the model and full-scale results shown by both microphone locations. This study, while somewhat qualitative, is

indicative of the results that may be obtained from tunnel and flight experiments that are carefully coordinated to quantify the effects of scale on rotorcraft noise. Success with this activity will lead to greater significance and usefulness of model data in determining the acoustic properties of a full-scale aircraft with less reliance on costly full-scale tests.

INTERIOR NOISE REDUCTION

Interior noise reduction studies are being conducted as indicated in Figures 2, 16, and 19 to achieve increased comfort of crew and passengers with minimum weight and cost penalties. Figure 18 outlines schematically some of the potential methods of reducing the noise and vibration levels within the cabin. A program is underway to quantify the sources of the noise and to identify the paths of the noise into the cabin.

Of particular importance is the structural-borne noise transmitted by the main rotor gear box and methods of controlling both the vibrations and noise due to this source. The development of validated predictive models of the effectiveness of various noise control treatments designed to withstand the physical and operational constraints of a typical rotorcraft flight environment will be evaluated based upon subjective response criteria developed for passenger environments. The passenger acceptance of aircraft interior noise and vibration as well as community reaction to the exterior noise are part of the LaRC program in acoustics and noise reduction.

Research on the interactive effects of broadband noise with multifrequency and multiaxis vibration has been conducted using the Langley Passenger Ride Quality Simulator (PRQA) (ref. 4). This research has resulted in a general model and design tool for prediction of passenger ride comfort within complex

ride environments (ref. 5). The basic elements of the ride comfort model are illustrated in Figure 19 for the particular case where the ride environment consists of interior noise combined with vibration in the vertical and lateral axes. The model uses empirically determined laws to compute discomfort produced by vibration in each axis individually, combines these to obtain combined axes discomfort, corrects for trip duration, and then applies a correction for noise discomfort. Output of the model is a single number index measured along a ratio scale (Disc Scale) of discomfort where a value of unity is equal to discomfort threshold. Research is continuing to develop model corrections for narrowband noise, i.e., noise with significant tonal content.

PSYCHOACOUSTICS

The underestimation of effects of the impulsive nature of some helicopter noise has often been singled out as the reason that present noise metrics inadequately predict human response to helicopter noise. Recent research such as reference 6, however, has indicated that other aspects of helicopter noise may be equally responsible. The psychoacoustic research program at Langley, as indicated in figures 2, 20, and 21 include both basic and applied studies to improve the quantifications of helicopter noise. Of particular interest in the basic program are the separate and combined influences of main rotor, tail rotor and engine noises. In other more applied studies the main interest is how well the annoyance due to the noise of present and future helicopters is predicted by current and proposed noise metrics.

ADDITIONAL RESEARCH AREAS

Two additional areas of rotorcraft research, not presently funded, are worthy of mention. Gear box noise is a major contributor to rotorcraft interior noise levels and is a prime focus in attempts to reduce these levels. The other area is engine noise. As the aerodynamic (rotating blade) sources of noise are reduced, turboshaft engine noise becomes significant and may represent a noise floor in the sense that airframe noise is considered a noise floor for CTOL aircraft. Present noise prediction methods for high-bypass-ratio jet engines may require modification for application to rotorcraft propulsion systems. Both of these noise sources are Lewis Center areas of responsibility and will undoubtedly become elements of NASA's rotorcraft acoustics research program.

SUMMARY

In summary, the NASA rotorcraft acoustics program is a cooperative activity involving Acoustics and Noise Reduction Division and USARTLE Structures Laboratory at Langley and the Helicopter and Powered Lift Division at Ames.

The program comprises model- and full-scale aeroacoustic experiments together with development of a comprehensive analytical model of rotorcraft noise generating processes. Additional program elements include interior noise reduction and noise metrics research at Langley.

Source noise reduction, a design-for-noise capability, interior noise control, and improved rotorcraft noise metrics constitute the basic thrusts of NASA's rotorcraft acoustics research program.

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- Leatherwood, J. D., Dempsey, T. K., and Clevenson, S. A.: A Design Tool for Estimating Passenger Ride Discomfort Within Complex Ride Environments. Human Factors, 1980, 22(3), 291-312.
5. Powell, Clemans A.: A Subjective Field Study of Helicopter Blade-Slap Noise. NASA Technical Memorandum 78758, July 1978.

ROTORCRAFT PROGRAM MILESTONES

ACOUSTICS

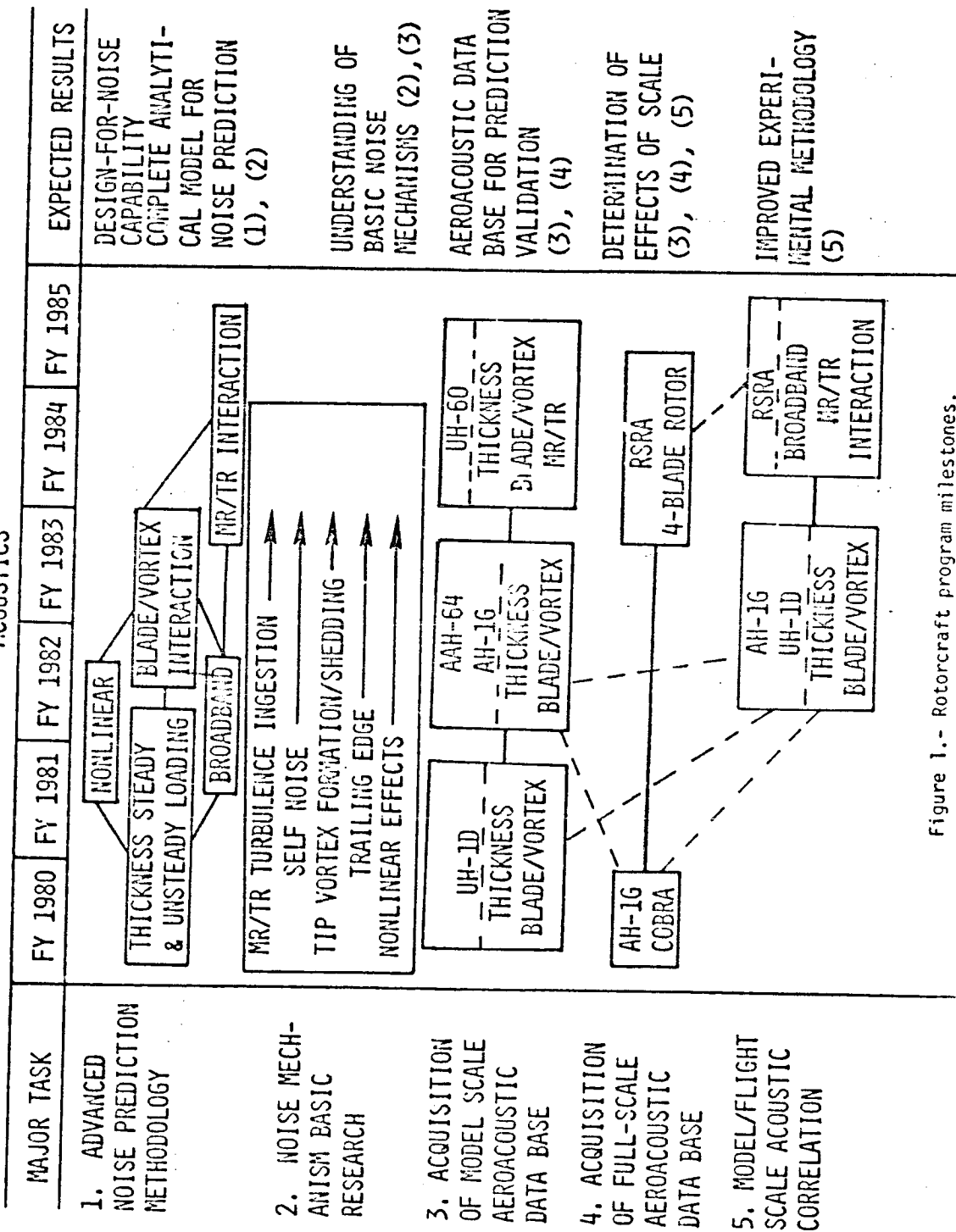


Figure 1.- Rotorcraft program milestones.

ROTORCRAFT PROGRAM MILESTONES(CONTINUED)

A. JUSTICS

MAJOR TASK	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985	EXPECTED RESULTS
6. INTERIOR NOISE REDUCTION	<pre> graph TD A[AIRBORNE TRANSMISSION] --> B[STRUCTUREBORNE TRANSMISSION] B --> C[CONTROL & OPTIMIZATION] C --> D[TREATMENT] D --> E[MR/TR BROADBAND] E --> F[REPEATITION RATE] </pre>						PREDICTION (6)
							CONTROL (6)
7. BASIC PSYCHOACOUSTIC RESEARCH	<pre> graph TD A[IMPULSIVITY] --> B[REPEATITION RATE] B --> C[BACKGROUND DETECTION] C --> D[UPDATED FLEET METRICS] </pre>						BASIC CHARACTERISTICS QUANTIFIED (7)
							IMPROVED METRICS (7), (8)
8. APPLIED PSYCHOACOUSTICS RESEARCH							

Figure 2.- Rotorcraft program milestones (continued).

EXECUTIVE SUMMARY OF ROTORCRAFT PROGRAMS

Acoustics

MAJOR TASK	DESCRIPTION	CONTACTS
1. ADVANCED NOISE PREDICTION METHODOLOGY	THE GOAL OF THIS ACTIVITY IS TO DEVELOP A DESIGN-FOR-NOISE CAPABILITY FOR ROTORCRAFT BY FORMULATING AND VALIDATING A COMPREHENSIVE ANALYTICAL MODEL OF HELICOPTER NOISE GENERATING MECHANISMS.	J. P. RAINEY/NTB/LARC 2648/505-42-13
2. NOISE MECHANISM BASIC RESEARCH	A DETAILED UNDERSTANDING OF INDIVIDUAL NOISE GENERATING MECHANISMS IS ESSENTIAL TO THE DEVELOPMENT OF AN ACCURATE PREDICTION CAPABILITY. A COMBINATION OF CONTRACTED AND INHOUSE RESEARCH IS DIRECTED AT THE BLADE/ VORTEX AND MAIN ROTOR/TAIL ROTOR INTERACTION PHENOMENA INCLUDING THE EFFECTS OF TIP SHAPE AND AT BROADBAND (NON-IMPULSIVE) NOISE GENERATION.	J. P. RAINEY/NTB/LARC 2648/505-42-13 AND 532-06-13 D. HOAD/LSAB/LARC 3611/505-42-23

Figure 3.- Executive summary of rotorcraft programs.

COMPARISON OF CALCULATED AND MEASURED FLYOVER SOUND PRESSURE LEVELS FOR AH-1G

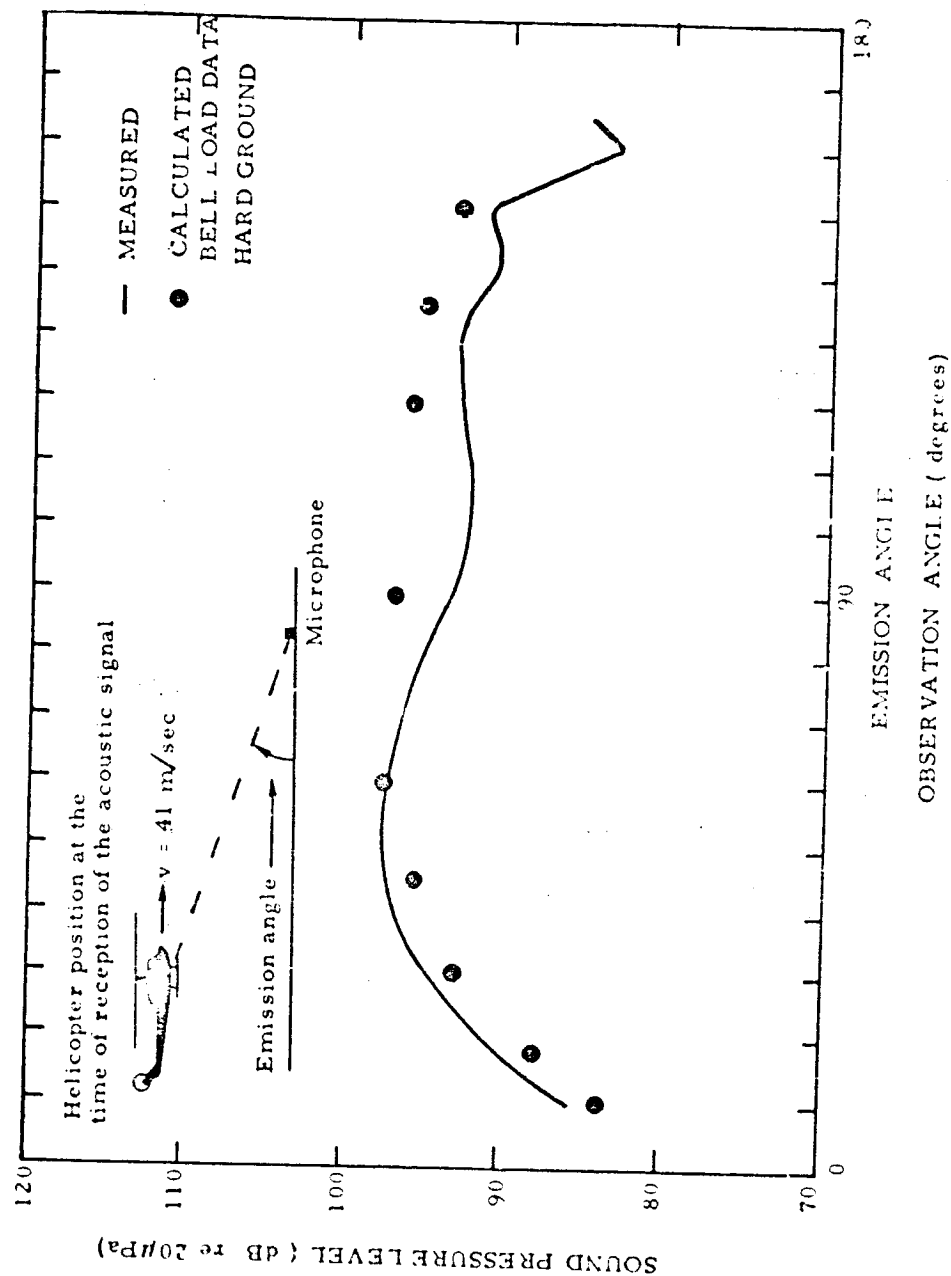


Figure 4.1 Comparison of calculated and measured flyover sound pressure levels for AH-1G.

COMPARISON OF CALCULATED AND MEASURED HARMONICS FOR AH-16

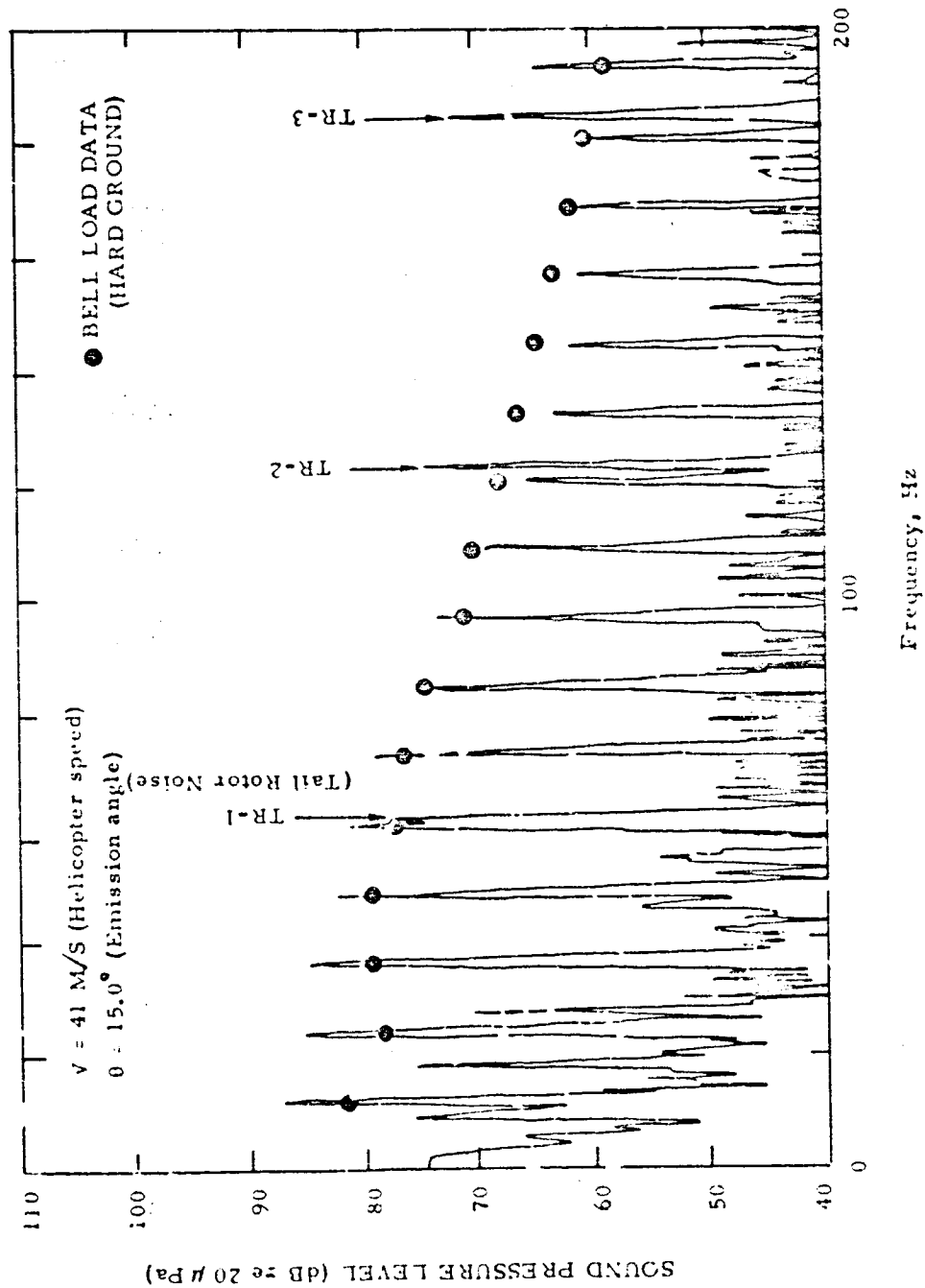


Figure 5.- Comparison of calculated and measured harmonics for AH-16.

BLADE SYSTEM THICKNESS NOISE COMPARISON

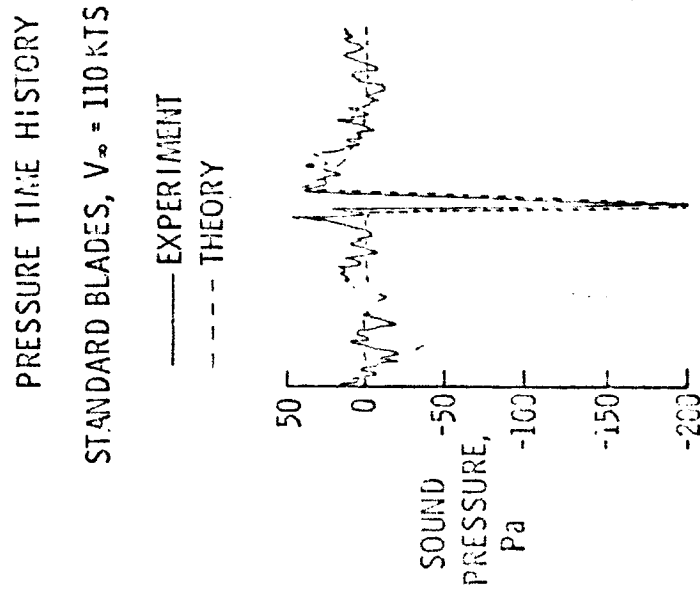


Figure 6.- Blade system thickness noise comparison.

BLADE SYSTEM THICKNESS NOISE COMPARISON

THEORY COMPARISON

STANDARD BLADES, $V_{\infty} = 110$ KTS

PRESSURE TIME HISTORY

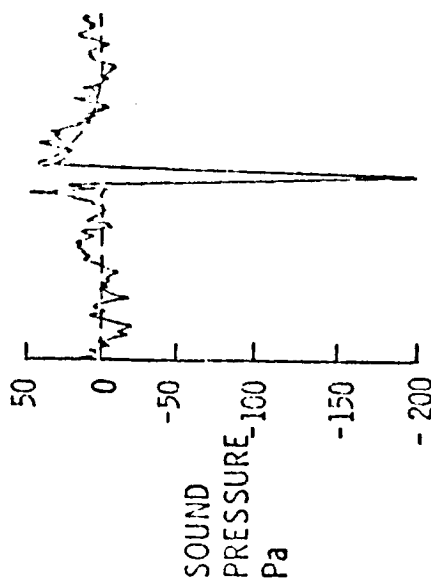
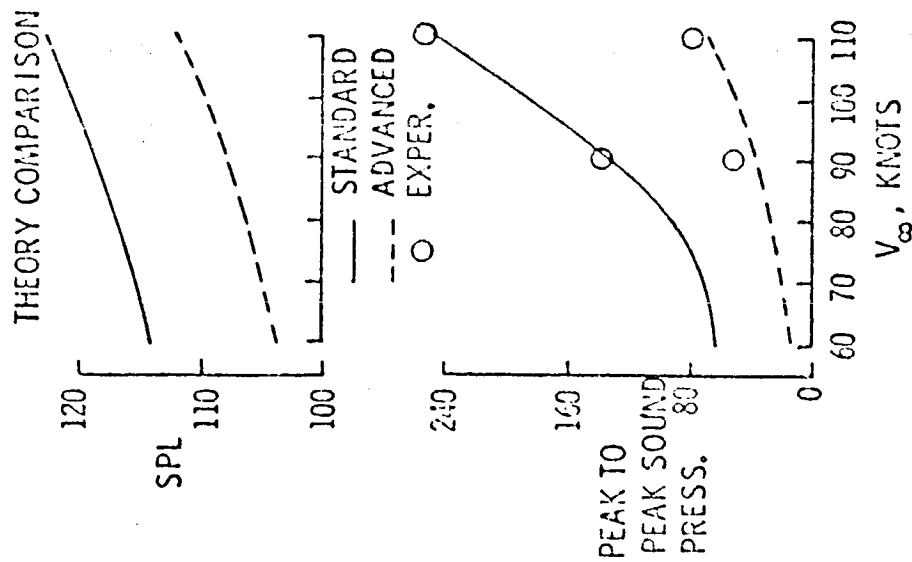


Figure 7.- Blade system thickness noise comparison.

BLADE/VORTEX INTERACTION NOISE

MODEL IN V-STOL TUNNEL

TIP SHAPES

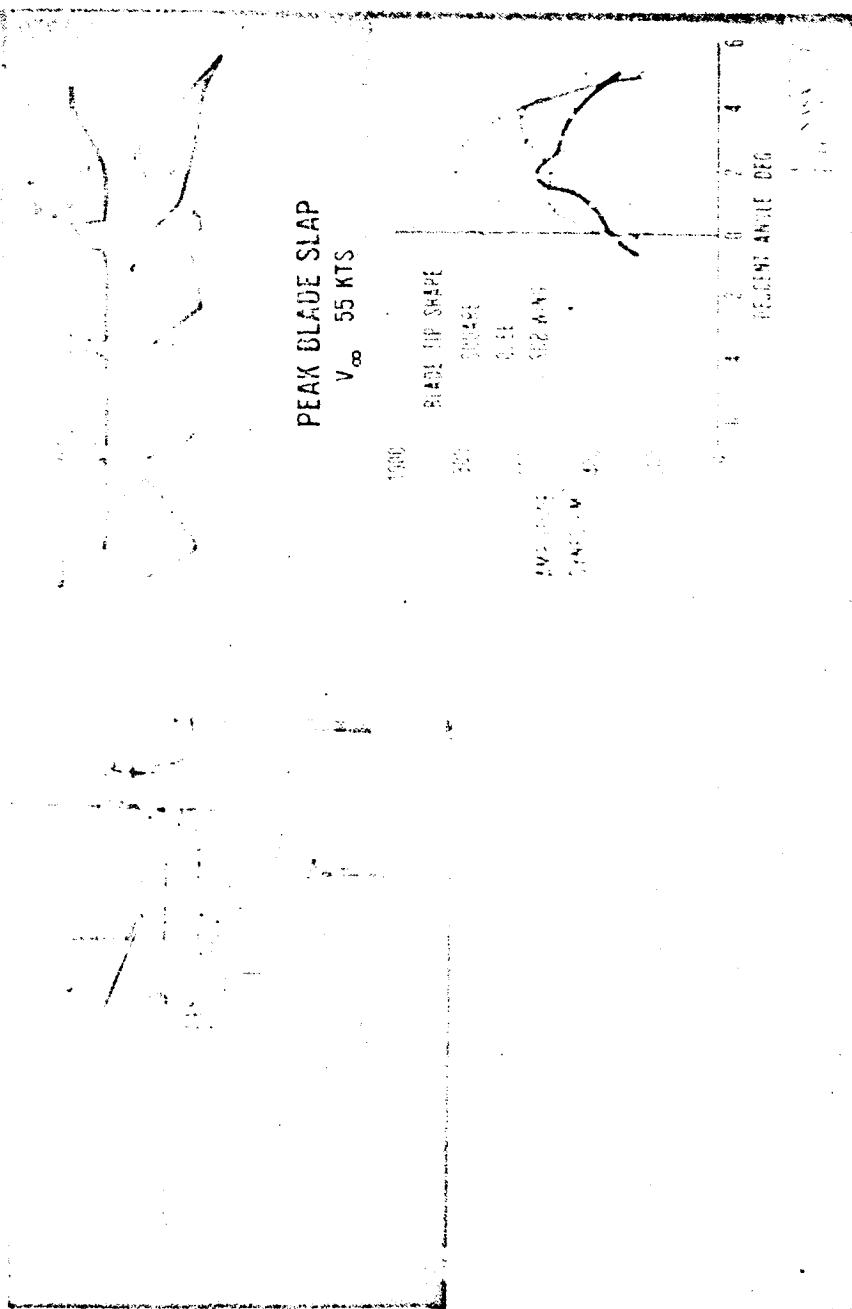


Figure 8.-Blade/vortex interaction noise.

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HELICOPTER NOISE CONTRIBUTIONS FROM UNSTEADY LOADING SOURCES

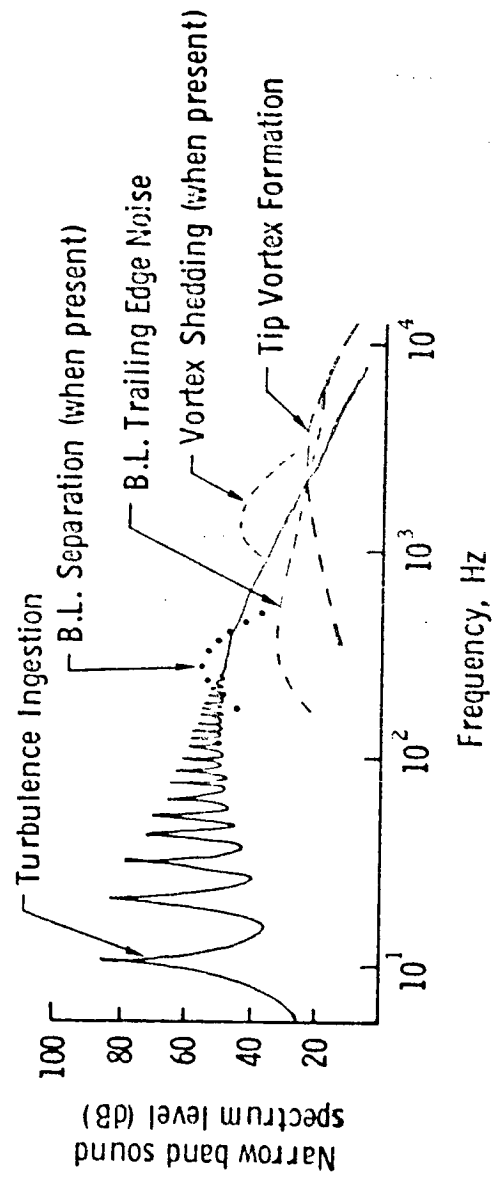


Figure 9.- Helicopter noise contributions from unsteady loading sources.

THICKNESS NOISE

STEADY LOADING NOISE

UNSTEADY LOADING NOISE

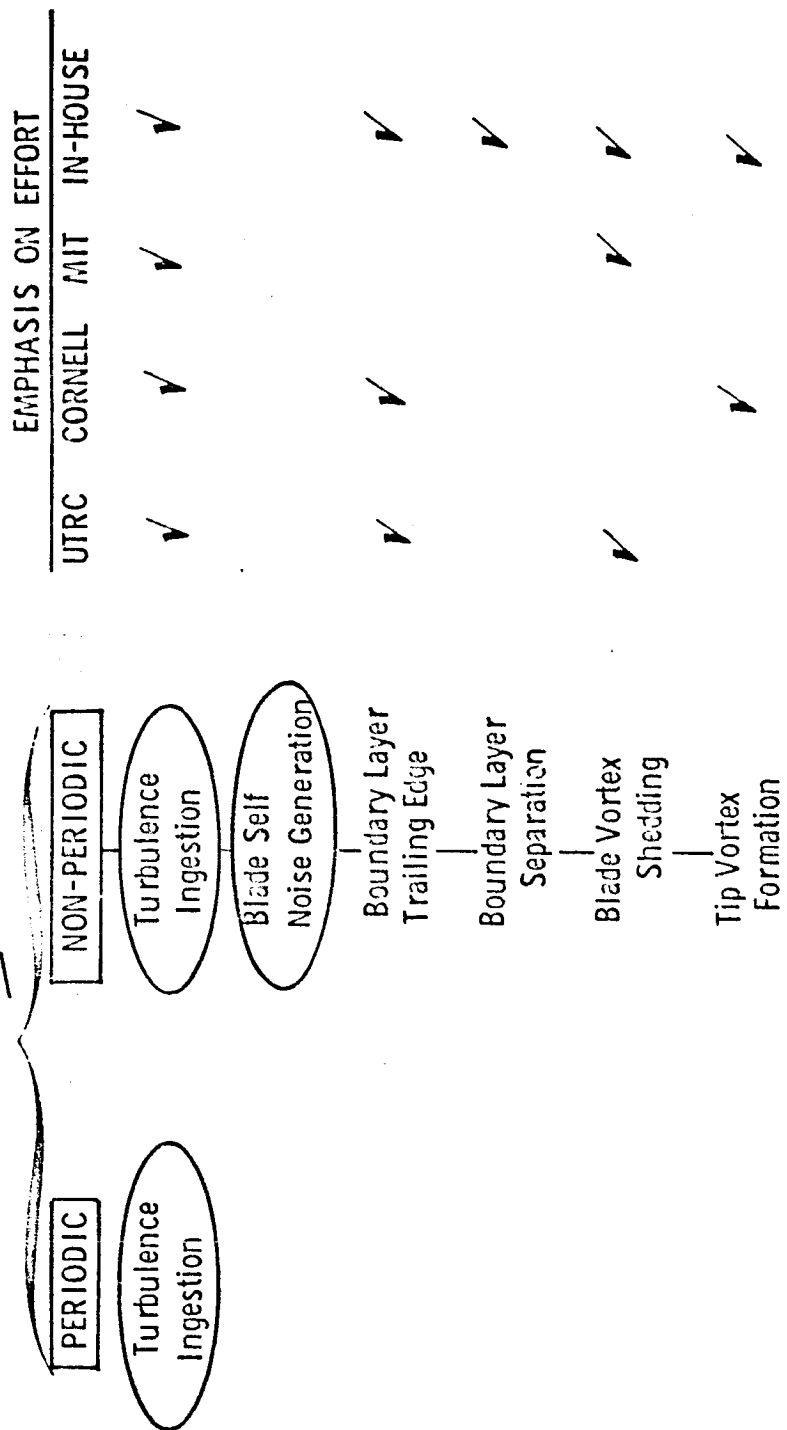


Figure 10.- Helicopter noise.

MAJOR TASK	DESCRIPTION	CONTACTS
3. ACQUISITION OF MODEL SCALE AEROACOUSTIC DATA BASE	THE PURPOSE OF THIS ACTIVITY IS TO ACQUIRE A HIGH QUALITY, MODEL SCALE, AEROACOUSTIC DATA SET FOR A VARIETY OF ROTOR SYSTEMS TO BE USED FOR VALIDATING PREDICTION TECHNIQUES, NOISE REDUCTION, AND FOR GUIDING COOPERATIVE ARC/LRC RSRA FLIGHT EXPERIMENTS. WORK WILL BE PERFORMED IN THE LANGLEY V/STOL TUNNEL.	J. P. RAHEY/NTB/LARC 2648/532-06-13 D. HOAD/LSAB/LARC 3611/505-42-23
4. ACQUISITION OF FULL-SCALE AEROACOUSTIC DATA BASE.	THE PURPOSE OF THIS ACTIVITY IS TO ACQUIRE A HIGH QUALITY, FULL SCALE AEROACOUSTIC DATA SET (AIR-TO-AIR AND AIR-TO-GROUND) TO BE USED FOR VALIDATING AND IMPROVING PREDICTION TECHNIQUES. THE COOPERATIVE EXPERIMENTS WILL BE CONDUCTED AT ARC USING THE RSRA WITH PRESSURE INSTRUMENTED BLADES AND YO-3A AIRCRAFT FOR AIR-TO-AIR MAPPING OF THE NOISE FIELD.	J. P. RAHEY/NTB/LARC D. HOAD/LSAB/LARC G. SHOCKEY/RSFIB/ARC 6576/532-03-11 AND 532-06-11

Figure 11.- Executive summary of rotorcraft programs (continued).

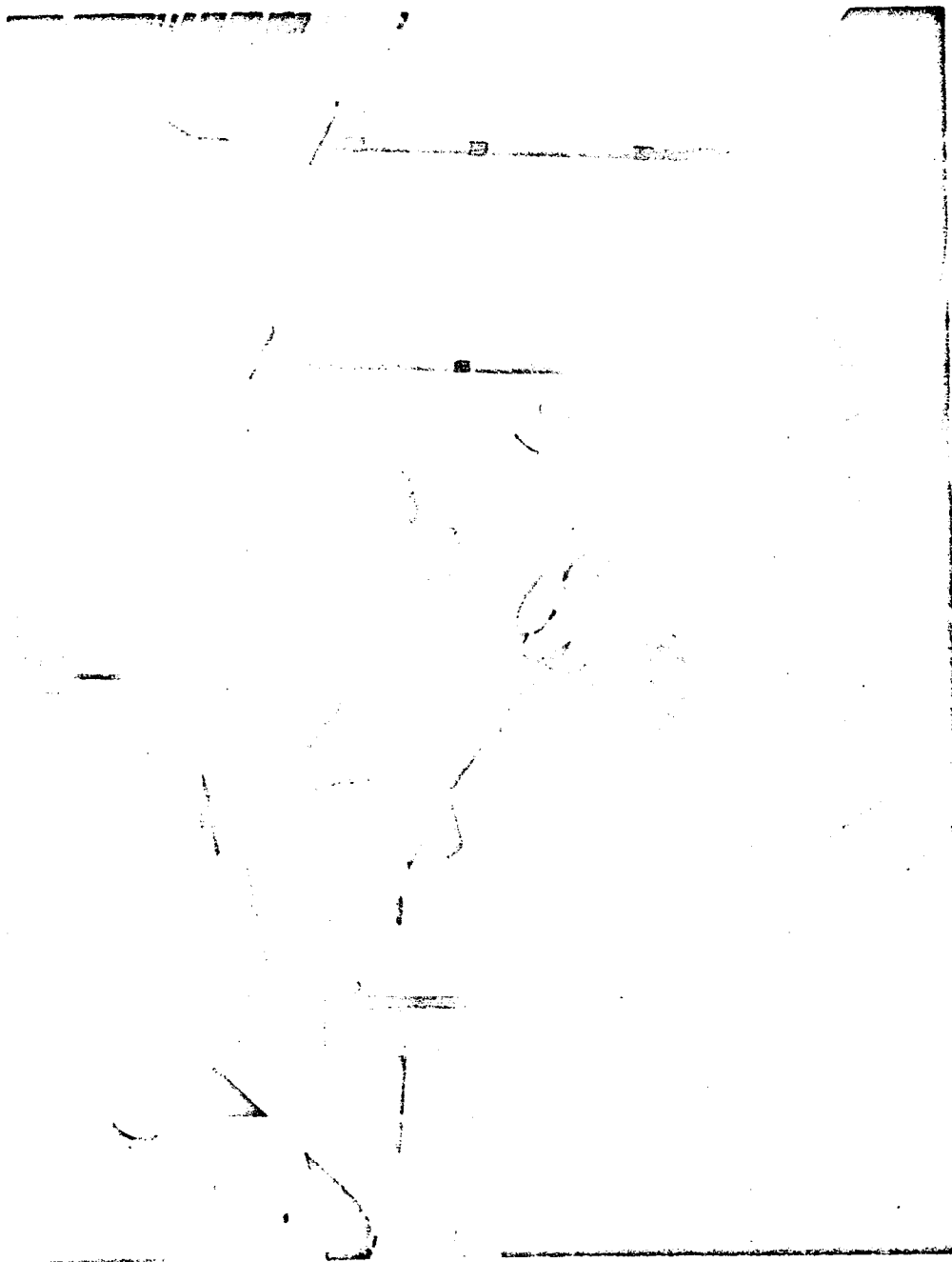


Figure 12.- RSHA model in V/SOL tunnel.

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AH-1G MODEL IN V/STOL TUNNEL

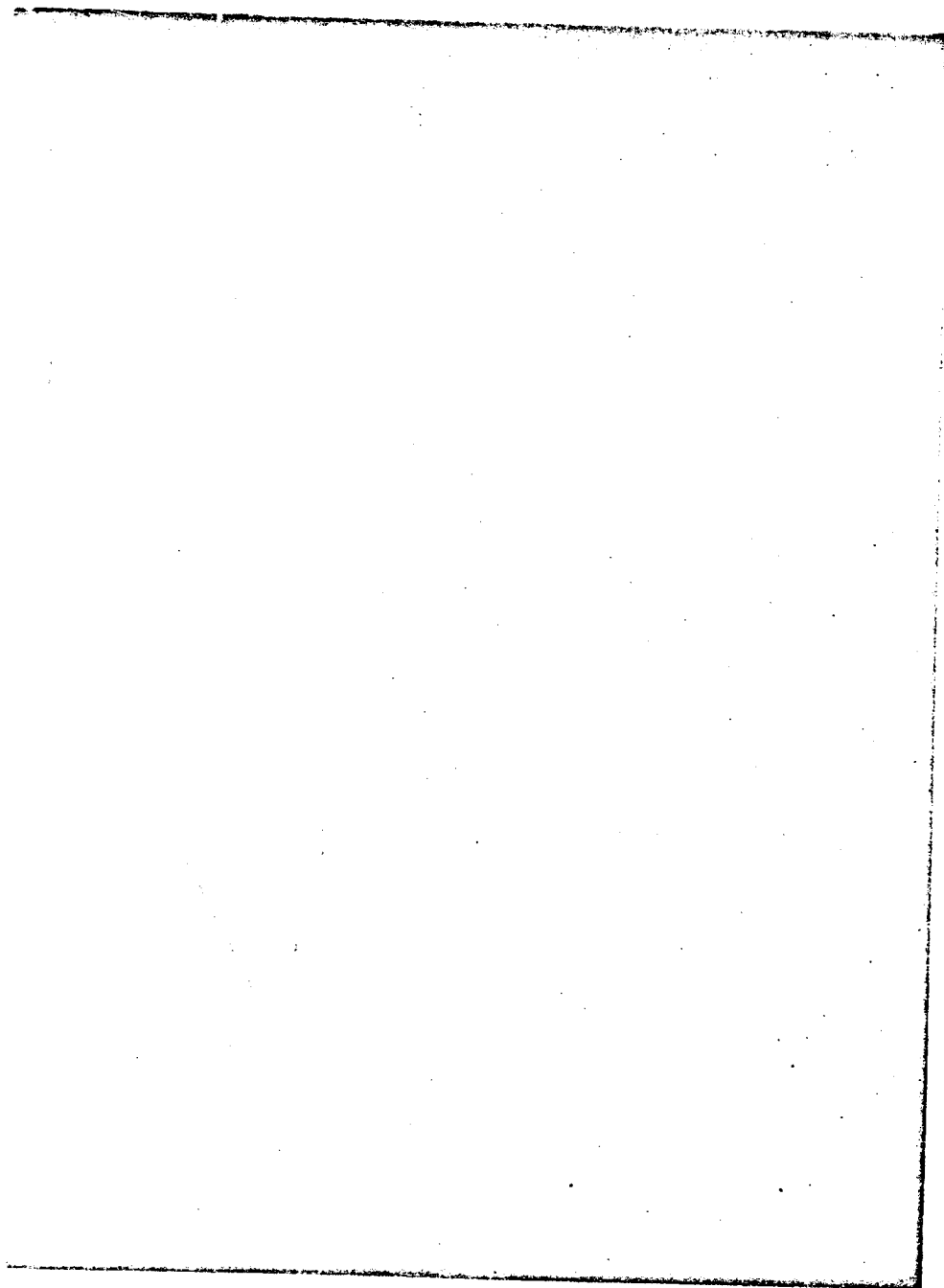


Figure 13.- AH-1G model in V/STOL tunnel.

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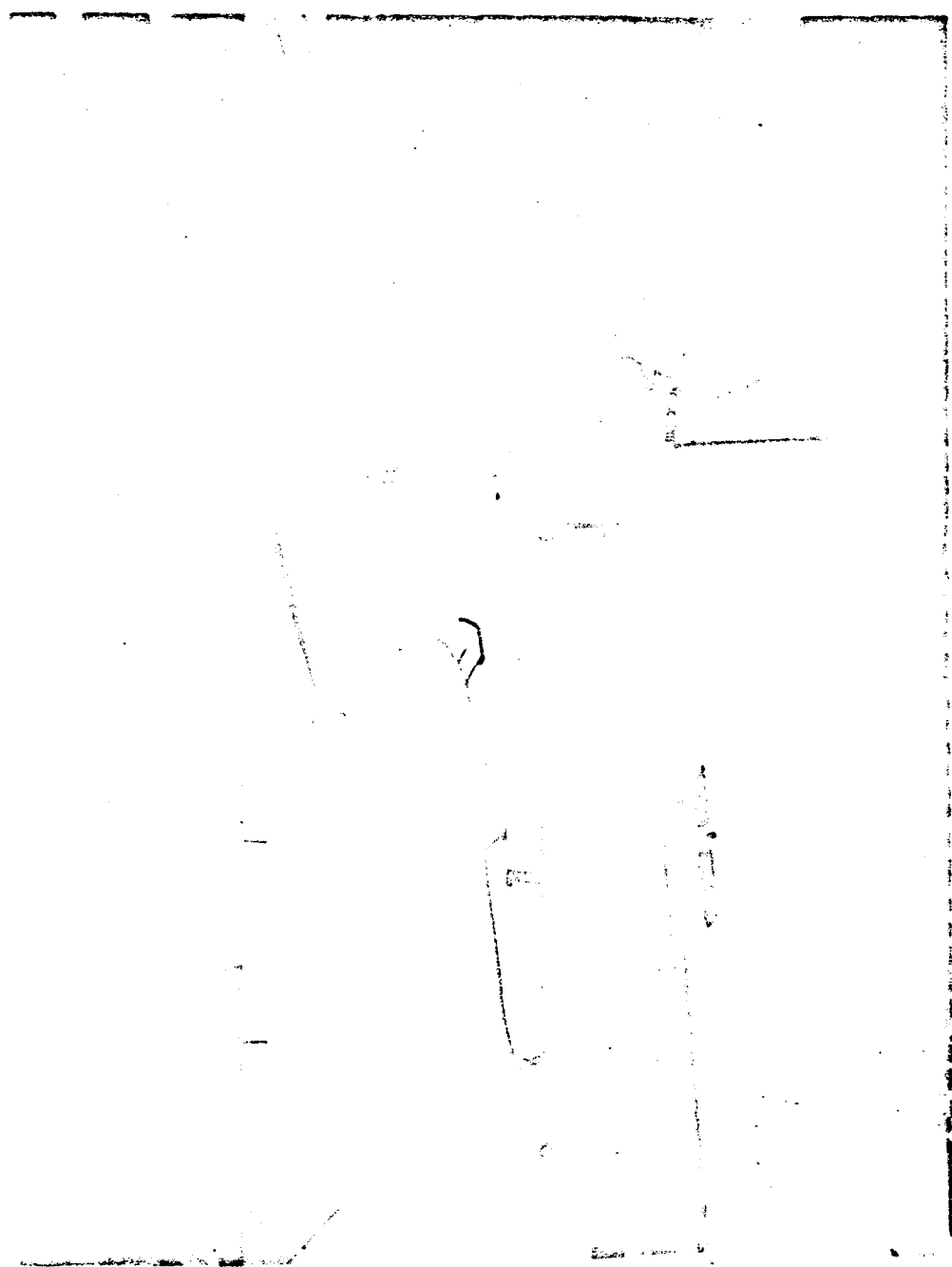


Figure 14.- UH-1D model in V/STOL tunnel.

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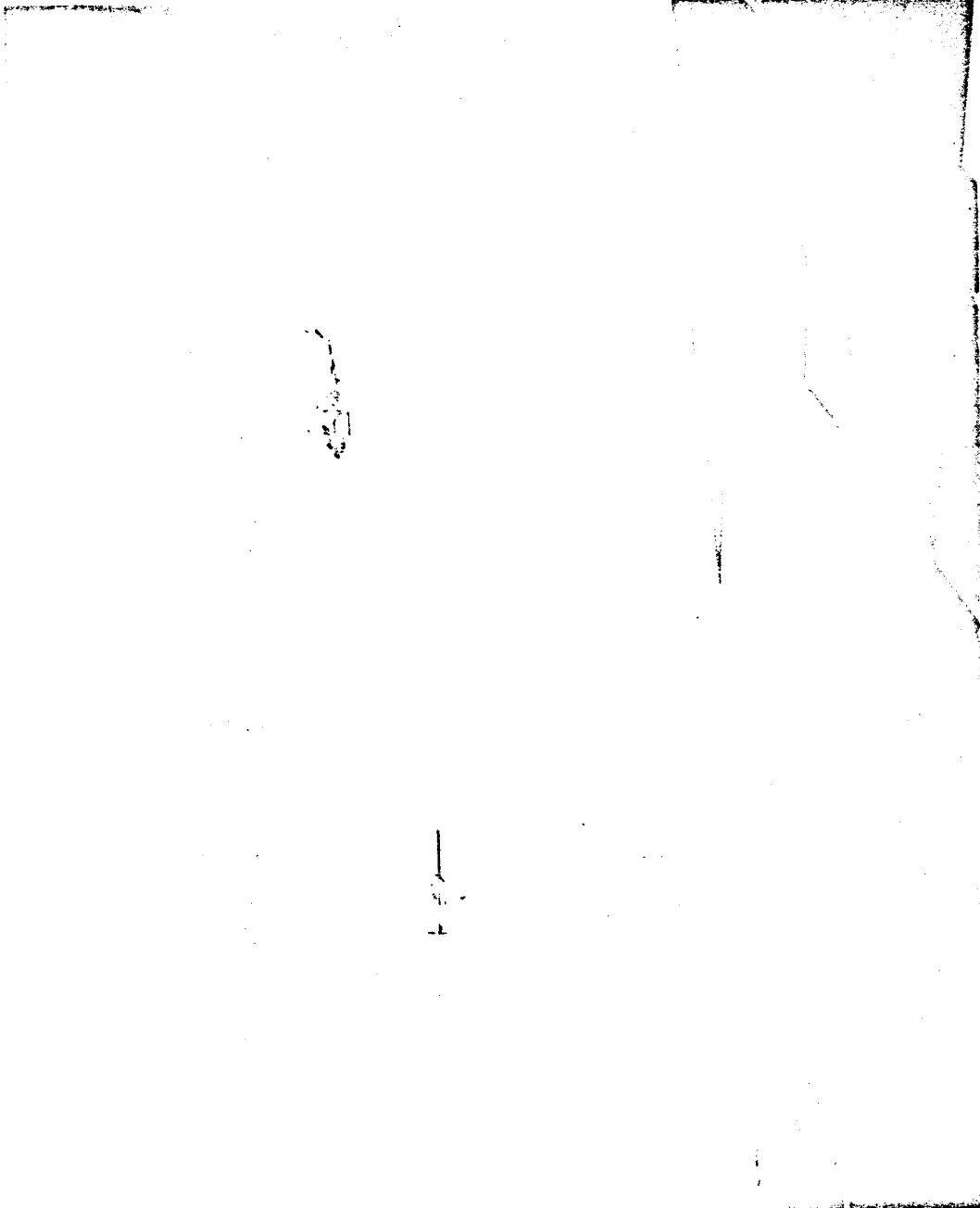


Figure 13.- The AH-1G station keeping on the W0 3.

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MAJOR TASK	DESCRIPTION	CONTACTS
5. MODEL/FLIGHT SCALE ACOUSTIC CORRELATION	THIS RESEARCH ENDEAVOR IS INTENDED TO PROVIDE A DATA BASE TO DEVELOP A CRITICAL UNDERSTANDING OF THE SCALE MODEL-TO-FLIGHT CORRELATION OF ROTOR ACOUSTICS. PRIMARILY RELATED TO BLADE/VORTEX INTERACTION NOISE, THIS PROGRAM CAN LEAD TO ADVANCED RESEARCH INTO IMPORTANT SCALING PARAMETERS.	D. HOAD/LSAB/LARC 3611/505-42-23
6. ROTORCRAFT INTERIOR NOISE REDUCTION	DEVELOP TECHNOLOGY FOR REDUCING INTERIOR NOISE OF ROTORCRAFT	D. G. STEPHENS/NEB/LARC 3561/526-06-13

Figure 16.- Executive summary of rotorcraft programs (continued).

BLADE-VORTEX INTERACTION STUDY AT LANGLEY V-STOL TUNNEL

FLIGHT TEST DATA COMPARISON, AH-1G

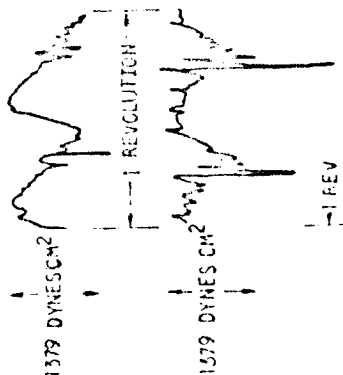
FLIGHT TEST



PRELIMINARY RESULTS

$V_f = 53$ KNOTS

DESCENT VELOCITY = 600 FT/MIN



$V_f = 50.7$ KNOTS

DESCENT VELOCITY = 650 FT/MIN

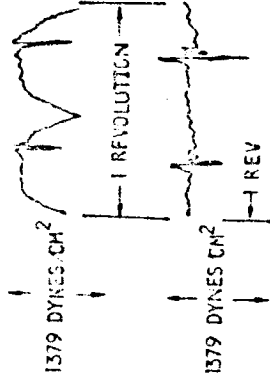


Figure 17.- Blade-vortex interaction study at Langley V-STOL tunnel.

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Figure 18.- Helicopter interior noise reduction.

RIDE COMFORT MODEL EXAMPLE

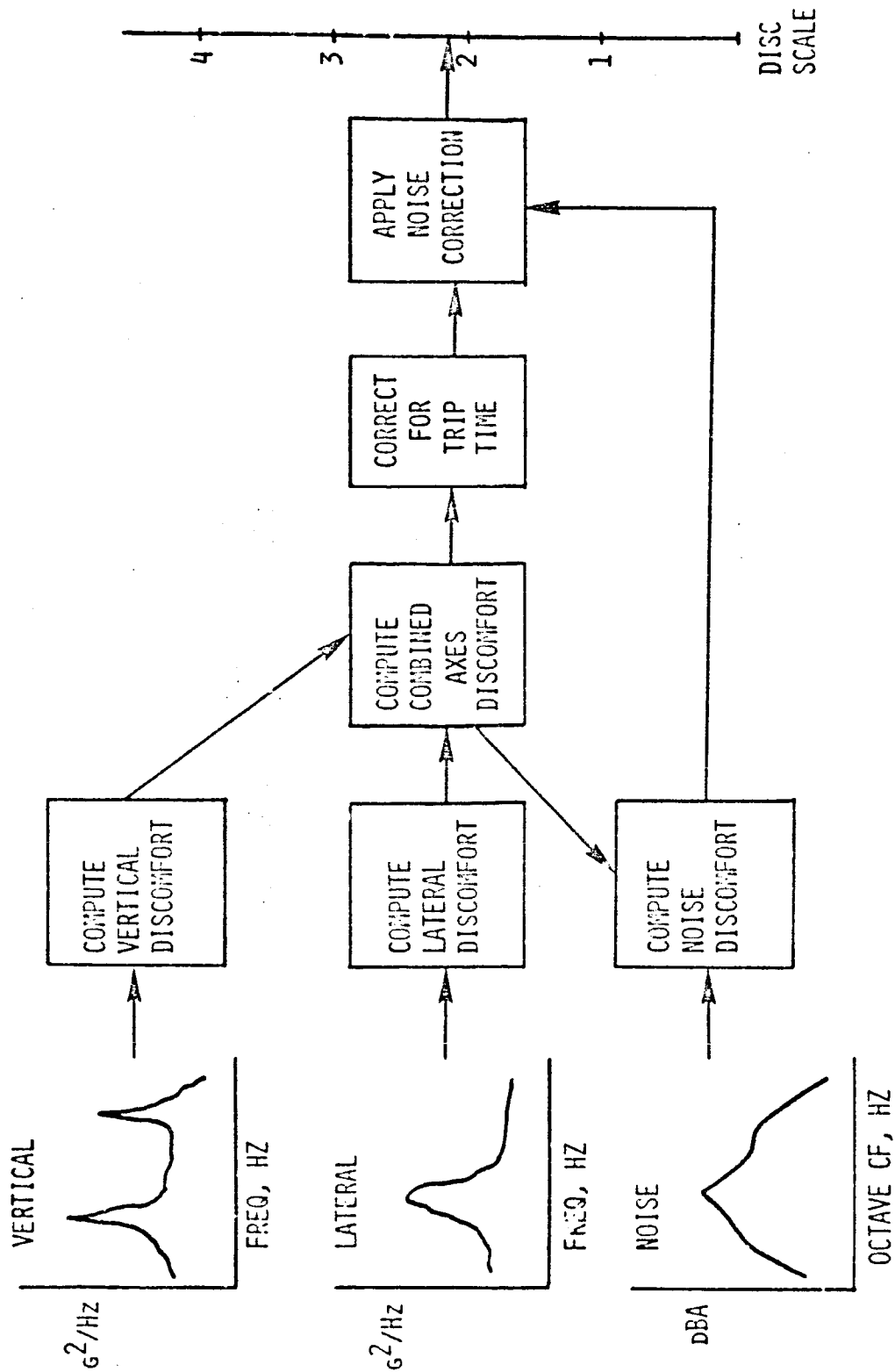


Figure 19.- Ride comfort model example.

MAJOR TASK	DESCRIPTION	CONTACTS
7. BASIC PSYCHO- ACOUSTIC STUDIES	THESE TESTS ARE TO PROVIDE AN UNDER- STANDING OF BASIC ANNOYANCE CHARACTERISTICS OF ROTORCRAFT NOISE FROM WHICH IMPROVED ANNOYANCE MODELS AND NOISE METRICS CAN BE DEVELOPED.	C. A. POWELL/NEB/LARC 3561/505-35-13-01
8. APPLIED PSYCHO- ACOUSTIC STUDIES	THE GOALS OF THESE PSYCHOACOUSTIC TESTS ARE TO DETERMINE AND IMPROVE, IF POSSIBLE, THE ANNOYANCE PREDICTION ABILITY OF METRICS FOR ROTORCRAFT NOISE.	C. A. POWELL/NEB/LARC 3561/505-35-13-01

Figure 26.- Executive summary of rotorcraft programs (continued).

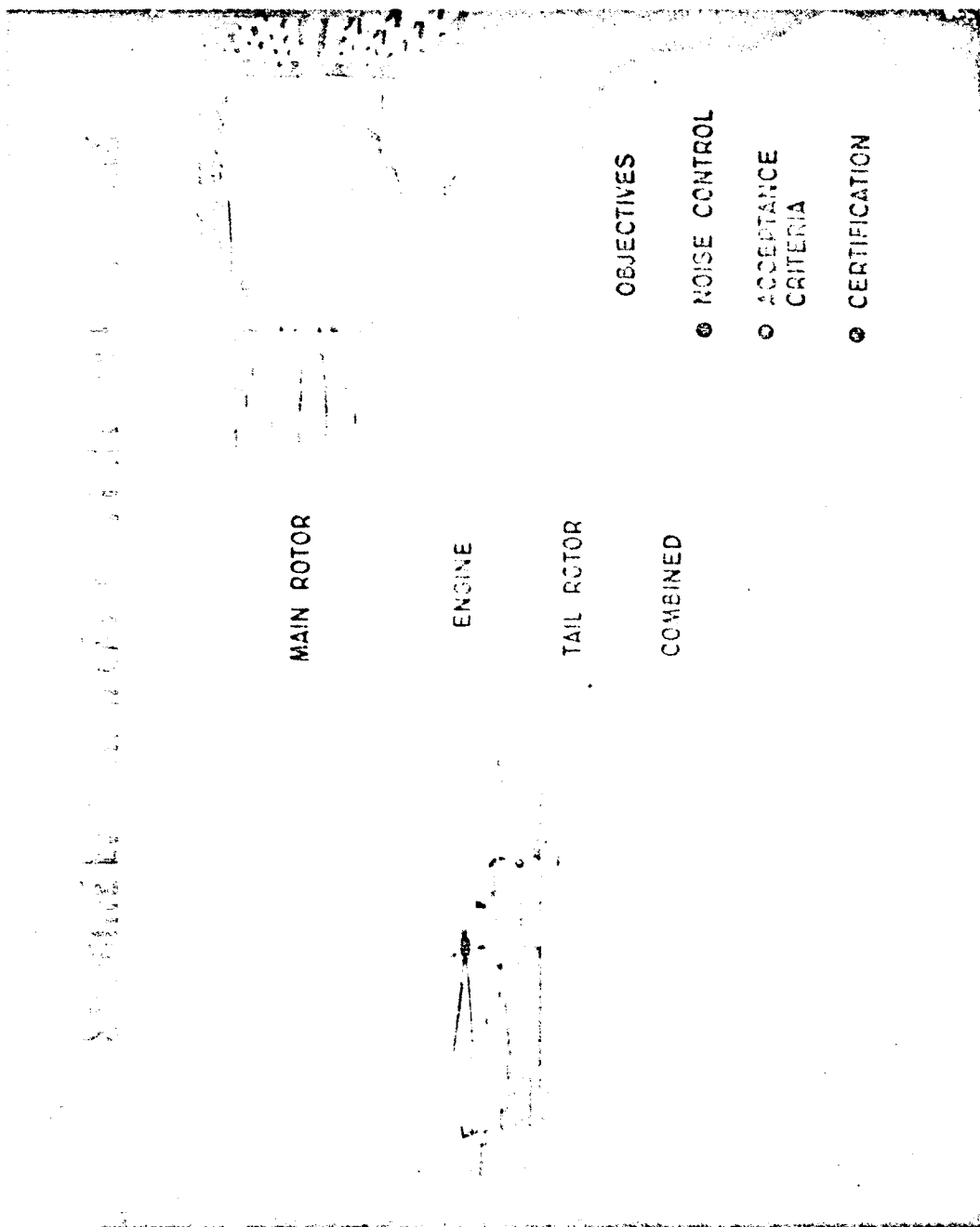


Figure 21.- Subjective evaluation of helicopter noise components.

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NASA VIBRATION REDUCTION PROGRAM

ROBERT J. HUSTON
NASA LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

SUMMARY

Vibration prediction methods. - A better capability to calculate vibrations of helicopters is a recognized requirement to reduce developmental risk and to improve ride comfort and fatigue life. To meet that need, Langley Research Center is developing a comprehensive basis for design analysis of vibrations of rotorcraft structures. Four steps are necessary. The first requires identifying techniques, procedures and decision criteria that may be successfully used in finite element airframe modeling. To that end, a current contracted effort will permit a team of NASA, NASA and Boeing Vertol specialists to do a complete finite element analysis of the CH-47 helicopter and compare the detailed analysis with shake test results. More important than the comparison of analysis and test results is the development of criteria for decisions on vibration design. A key part of this study are the reviews of the results by other helicopter companies in order that a general consensus can be obtained on the criteria for successful application of finite element airframe model for vibration analysis. This effort is expected to be completed by the end of 1982.

A key point recognized in the study to date should be made. In the past, finite element modeling and test correlation have been based on post design information. Frequently, short cuts and simplifications in the structural modeling were taken in the interest of economy. However, during the design of the airframe, a detailed finite element model is developed for static loads in order to properly stress and size structural members. This model, with the addition of the mass distributed from the "weights" department, is all that is necessary to develop an extremely detailed dynamic model. Therefore, a finite element airframe model suitable for vibration analysis may be obtained during the airframe design at only a marginal increase in cost.

The second step is to develop procedures to integrate finite element airframe models with rotor models for vibration analysis. Historically, methods for calculating these vibrations have been based on separate treatment of the rotor and the airframe. Such approaches may miss key system interactions. Published analytical methods accounting for coupling between the rotor and the

airframe are incomplete. An in-house team has formulated a complete computational procedure for practical analysis of vibrations of coupled rotor/airframe systems. Attention is directed to treatment of the airframe and the procedure is commensurate with requirements for analytical support of structural design throughout the industrial design process. The rotor is represented by a set of general linear differential equations with periodic coefficients which may be specialized to represent any rotor undergoing small vibrations with reference to an arbitrary trim state. Equations describing the rotor can be derived analytically or numerically from current or advanced mathematical models of rotors. The airframe is assumed to be represented by a typical finite-element analysis such as NASTRAN. The mathematical foundation of the procedure is the harmonic balance method of solution where the system vibratory responses are assumed to involve only a limited number of harmonics of the rotor rotational speed. The airframe participation is represented as a forced response in the manner traditionally discussed as impedance methods and mobility methods. The procedure will be reported in a NASA research paper in the near future.

The third step in obtaining a comprehensive basis for design analysis of vibrations is to develop a rotor dynamics model suitable for rotor structural design. This model should be the simplest that includes the rotor mechanisms essential for vibration analysis. The rotor blade, in the rotor system model, will be treated as a general structure and not restricted by beam theory. This effort has been initiated and is expected to be completed by the end of 1983.

The fourth step is for the rotorcraft industry to begin to exercise this new generation of analytical models. This implies that a management decision is made to emphasize design for low vibration in the preliminary and detailed design phases of development of any new rotorcraft. This also means shifting the emphasis on vibration reduction from dynamic department "fixes" to designing out vibration in the structures department.

Vibration control methods. - Concurrent with efforts to develop a better capability to calculate vibrations of rotorcraft, studies to develop and assess various concepts with a potential for modification of vibration or load characteristics must continue. At both the Langley Research Center and the Ames Research Center, wind tunnel experiments are correlated with available theory to evaluate various concepts including aeroelastically conformable rotor blades, higher harmonic blade control, closed loop feedback to controls, individual blade control, and vibration absorber devices. Included in this program are flight experiments to evaluate the

potential of concepts shown to have high potential. One such flight experiment under contract to Langley is to evaluate the use of closed loop feedback of higher harmonic control on a Hughes 500 (OH-6) helicopter. This concept is expected to fly before the end of 1981.

Advanced vibration suppression rotor. - Analytical research and assessment studies are underway at the Ames Research Center to select the most promising advanced flight research rotors from available rotor systems technology. This effort has now become an integral part of a cooperative plan with the Army (RTL) wherein an advanced flight research rotor would be designed and built, based in part on the Army's Integrated Technology Rotors. The objective is to demonstrate a research rotor capable of quiet, efficient and smooth performance at high cruise speeds, while still retaining sufficient versatility so that additional flight investigations may be performed using the unique capabilities of the RSRA. The specific rotor concept will be selected by 1984. A new initiative by NASA will be required by that time.

Rotor deicing. - A program is underway at the Ames Research Center to evaluate and verify the aerodynamic characteristics of a pneumatic deicing boot concept using a NASA UH-1H helicopter and an instrumented/booted Army rotor. Included are the necessary preflight investigations, followed by the performance of flight tests to measure the effectiveness and efficiency of this deicing system; assess the rotor deicing technology and identify critical system needs. The assessment will be completed in 1982. Future work will be defined at that time.

VIBRATION REDUCTION

MAJOR TASKS	DESCRIPTION	CONTACTS/RTOP
1. VIBRATION PREDICTION METHODS-I (ON GOING PROGRAM)	Industry consensus on applicability of finite element models to a modern helicopter airframe through a comparison of analysis and shake tests results. Document decision criteria, model and test guidelines.	W. C. Walton, Jr./Configuration Aeroelasticity Branch/LRC/2661 505-42-13
2. VIBRATION PREDICTION METHODS-II (ON GOING PROGRAM)	Formulate a comprehensive basis for rotor analytical model and rotor/airframe coupling, which when used with finite element airframe models is suitable for design analysis of helicopter rotor and airframe vibrations.	W. C. Walton, Jr./Configuration Aeroelasticity Branch/LRC/2661 505-42-13
3. VIBRATION CONTROL METHODS OR DEVICES (ON GOING PROGRAM)	Theory, wind tunnel and flight experiments to develop and assess various vibration and load modification concepts including active higher harmonic control, aeroelastically conformable rotors and vibration absorber devices.	W. H. Young, Jr./Configuration Aeroelasticity Branch/LRC/2661 505-42-13 W. JOHNSON, Low Speed Aircraft Research Branch/ARC/5043 - J. BIGGERS/Rotor Systems Flight Investigations Branch/ARC/6576 505-42-21/532-03-11/532-06-11

MAJOR TASKS	DESCRIPTION	CONTACTS/RTOP
4. ADVANCED VIBRATION SUPPRESSION ROTOR (FLIGHT RESEARCH ROTOR) (ON GOING PROGRAM)	<p>Analytical research and assessment studies are underway to select the most promising advanced flight research rotors from available rotor systems technology. This effort has now become an integral part of a cooperative plan with the Army (RTL) wherein an advanced flight research rotor would be designed and built, based in part on the Army's Integrated Technology Rotors. The objective is to demonstrate a research rotor capable of quiet, efficient and smooth performance at high cruise speeds, while still retaining sufficient versatility so that additional flight investigations may be performed using the unique capabilities of the RSRA.</p>	L. A. Haslim/Rotor Systems Flight Investigations Branch ARC/6575/532-06-11/532-03-11
5. ROTOR DEICING (ON GOING PROGRAM)	<p>A program is underway to evaluate and verify the aerodynamic characteristics of a pneumatic deicing boot concept using a NASA UH-1H helicopter and an instrumented/booted Army rotor. Included are the necessary pre-flight investigations, followed by the performance of flight tests to measure the effectiveness and efficiency of this deicing system; assess the rotor deicing technology and identify critical system needs.</p>	L. Haslim/Rotor Systems Flight Investigations Branch/ARC/6565/ 532-06-11

VIBRATION REDUCTION

Major Task	Description	Contact/RIOPs
6. AEROELASTICITY	<p>Experimental and analytical research is being conducted on aeroelastic stability characteristics of advanced rotorcraft. The experimental work involves flight tests and full scale and small scale wind tunnel tests to define aeroelastic phenomena and to obtain data for correlation of theories. The analytical work involves development of models for accurate prediction of dynamic stability. Future configurations to be investigated include bearingless helicopter rotors (particularly full scale BMA tests) and tilting propellers.</p>	<p>W. JOHNSON/LOW SPEED AIRCRAFT RESEARCH BRANCH/ ARC/5043</p> <p>J. BIGGERS/ROTOR SYSTEMS FLIGHT INVESTIGATIONS BRANCH/ARC/6576</p> <p>505-42-11 505-42-21 532-03-11</p>
7. AEROELASTIC AND LOADS	<p>Experimental and analytical research is being conducted on vibration and loads characteristics of advanced rotorcraft. The analytical work involves development of models for accurate prediction of rotor loads and rotor-induced vibration. The experimental work involves full scale and small scale wind tunnel tests, to define the dynamic phenomena; to obtain data for correlation with theory; and to measure the loads and vibration of new configurations. Flight tests will be conducted with the BMA, to make inflight measurements of loads and vibrations. Also, flight measurements from highly instrumented rotor blades will be used to provide data for correlation with loads predictions.</p>	<p>W. JOHNSON/LOW SPEED AIRCRAFT RESEARCH BRANCH/ ARC/5043</p> <p>J. BIGGERS/ROTOR SYSTEMS FLIGHT INVESTIGATIONS BRANCH/ARC/6576</p> <p>505-42-21 532-03-11 532-06-11</p>

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VIBRATION PREDICTION METHODS

OBJECTIVE: DEVELOP A COMPREHENSIVE BASIS FOR DESIGN ANALYSIS
OF VIBRATIONS OF ROTORCRAFT STRUCTURES

PROCESS: ESTABLISH INDUSTRY CONSENSUS ON VALIDITY OF FINITE
ELEMENT AIRFRAME MODEL (IN PROCESS)

DEVELOP PROCEDURES TO INTEGRATE FINITE ELEMENT
AIRFRAME WITH ROTOR MODELS

- o EXISTING ROTOR MODELS
- o ADVANCED ROTOR MODELS

(COMPLETED)

DEVELOP ROTOR MODELS APPROPRIATE FOR STRUCTURAL DESIGN

- o ROTOR SYSTEM MODEL
- o GENERALIZED BLADE STRUCTURAL MODEL

(INITIATED)

INDUSTRY EXERCISE ANALYTICAL MODELS

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**VIBRATION PREDICTION METHODS-I
AIRFRAME MODELING/TEST ASSESSMENT**

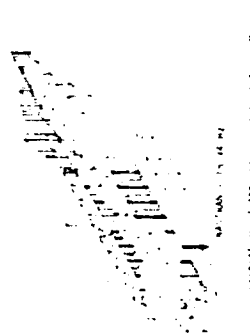
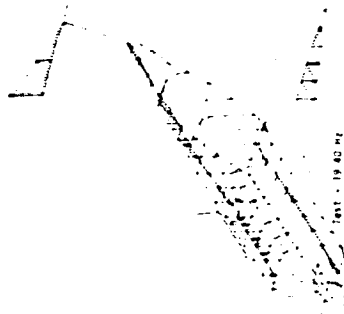


**SHAKE TESTS
OF MODELED
AIRFRAME**

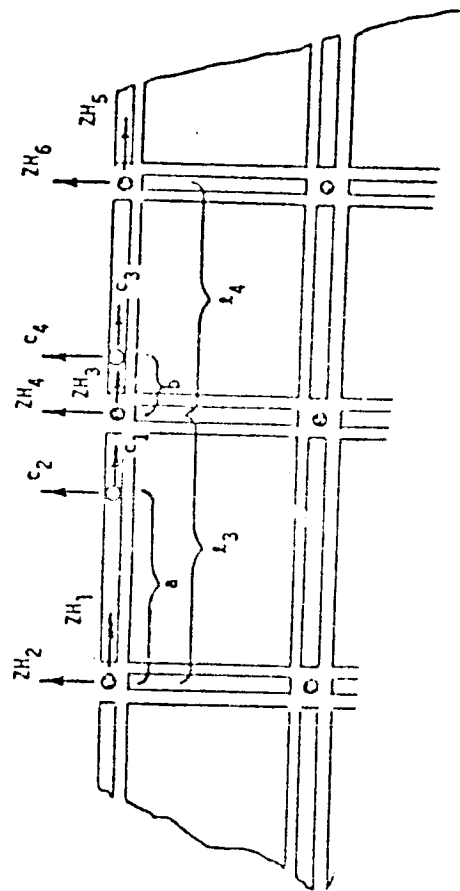
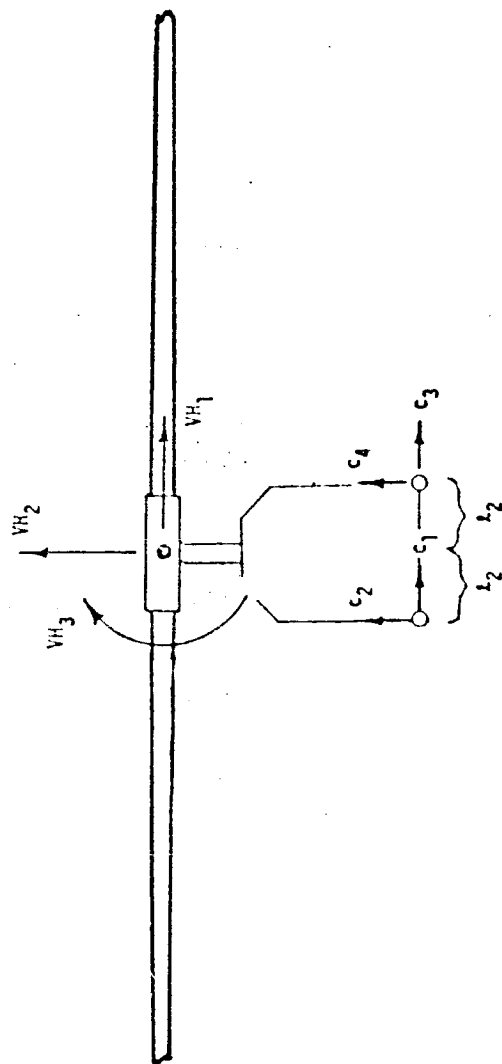
**CORRELATE
& DOCUMENT
MODEL/TEST
GUIDELINES**

**FINITE ELEMENT
ANALYSIS OF
AIRFRAME BY
NASA/INDUSTRY
TEAM**

**REVIEW PAST
FINITE ELEMENT &
TEST
CORRELATION**



WITH ROTOR MODELS



COMPLETED - A FORMULATION OF ROTOR/AIRFRAME COUPLING FOR DESIGN ANALYSIS
OF VIBRATIONS OF HELICOPTER AIRFRAMES

- BETTER CAPABILITY TO CALCULATE VIBRATIONS OF HELICOPTERS A RECOGNIZED REQUIREMENT
- PREVIOUS METHODS INSUFFICIENT FOR INDUSTRIAL DESIGN CALCULATIONS
 - SEPARATE TREATMENT OF ROTOR AND AIRFRAME
 - EMPHASIS ON ROTORAIRFRAME ONLY CASUALLY ADDRESSED
- DRAFT PAPER BY IN-HOUSE TEAM
 - COMPLETE COMPUTATIONAL PROCEDURE FOR COUPLED ROTOR/AIRFRAME VIBRATIONS
 - EMPHASIS ON AIRFRAME
 - CLEAR AND THOROUGH DISCUSSION OF ESSENTIAL MECHANICS
 - MATHEMATICAL FORMULATION FACILITATING COMPUTER IMPLEMENTATION
- THIS FORMULATES AND BRINGS TOGETHER AN ADEQUATE THEORETICAL BASIS AND EXPOSITION OF COMPUTATIONAL STEPS FOR HELICOPTER COMPANY STRUCTURAL DEPARTMENTS TO ACCOUNT FOR VIBRATIONS IN DESIGN

VIBRATION CONTROL METHODS

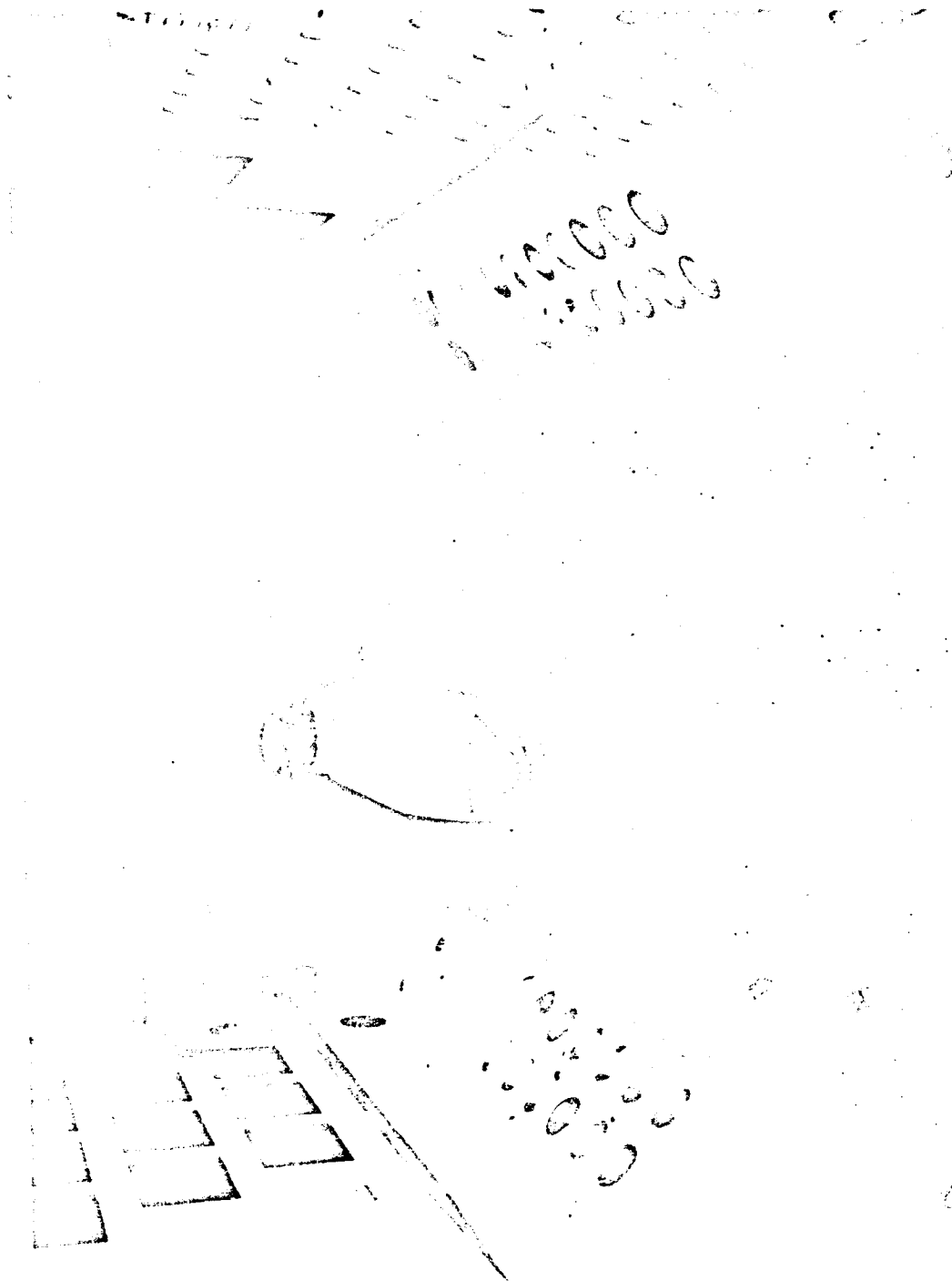
OBJECTIVES: EVALUATE VARIOUS VIBRATION AND LOAD MODIFICATION
CONCEPTS WITH POTENTIAL FOR EFFICIENT VIBRATION CONTROL

PROCESS: THEORY AND WIND TUNNEL EXPERIMENTS TO EVALUATE:

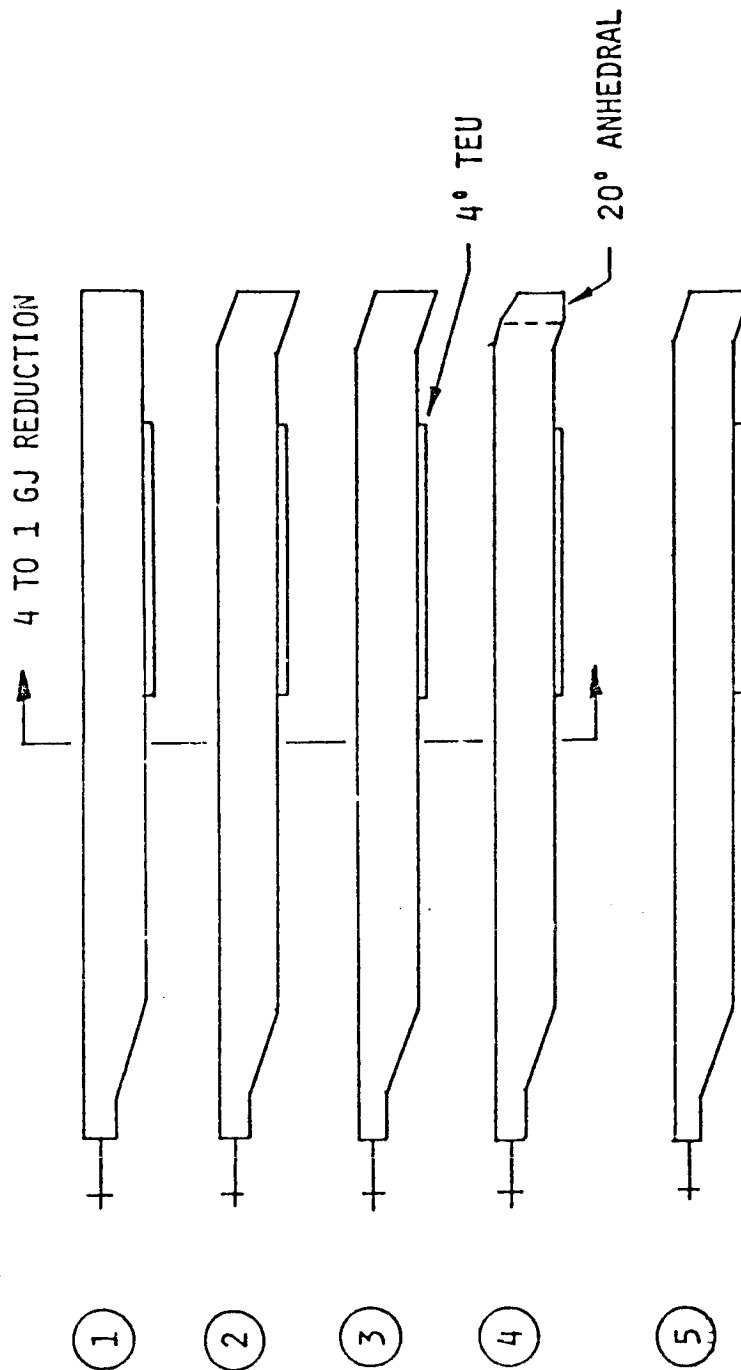
- o AEROELASTICALLY CONFORMABLE ROTOR BLADE
- o HIGHER HARMONIC BLADE CONTROL
- o CLOSED LOOP FEEDBACK TO CONTROL
- o INDIVIDUAL BLADE CONTROL
- o VIBRATION ABSORBER DEVICES

FLIGHT EXPERIMENT TO EVALUATE CONCEPTS

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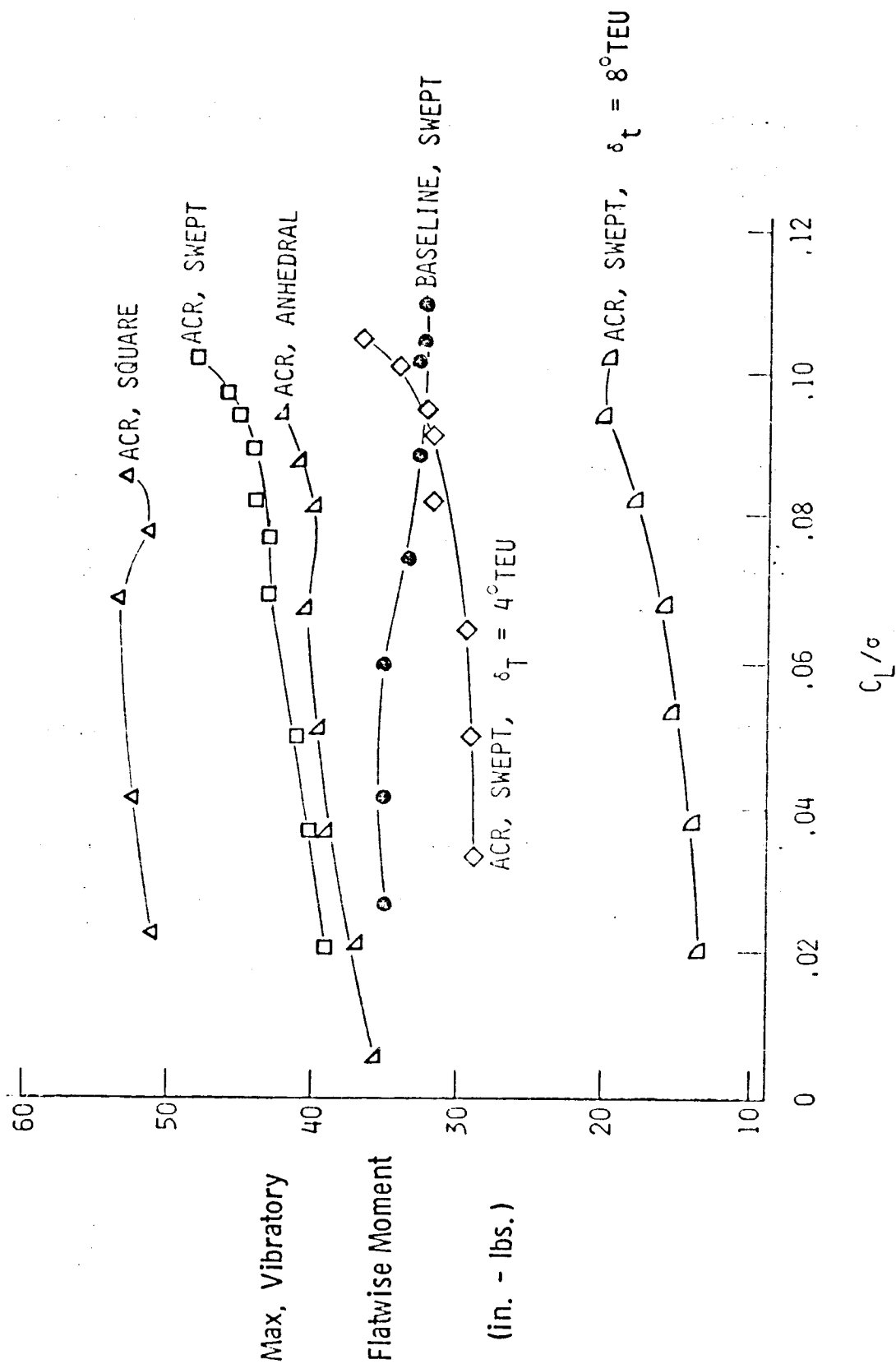


AEROELASTICALLY CONFORMABLE ROTOR CONFIGURATIONS TESTED

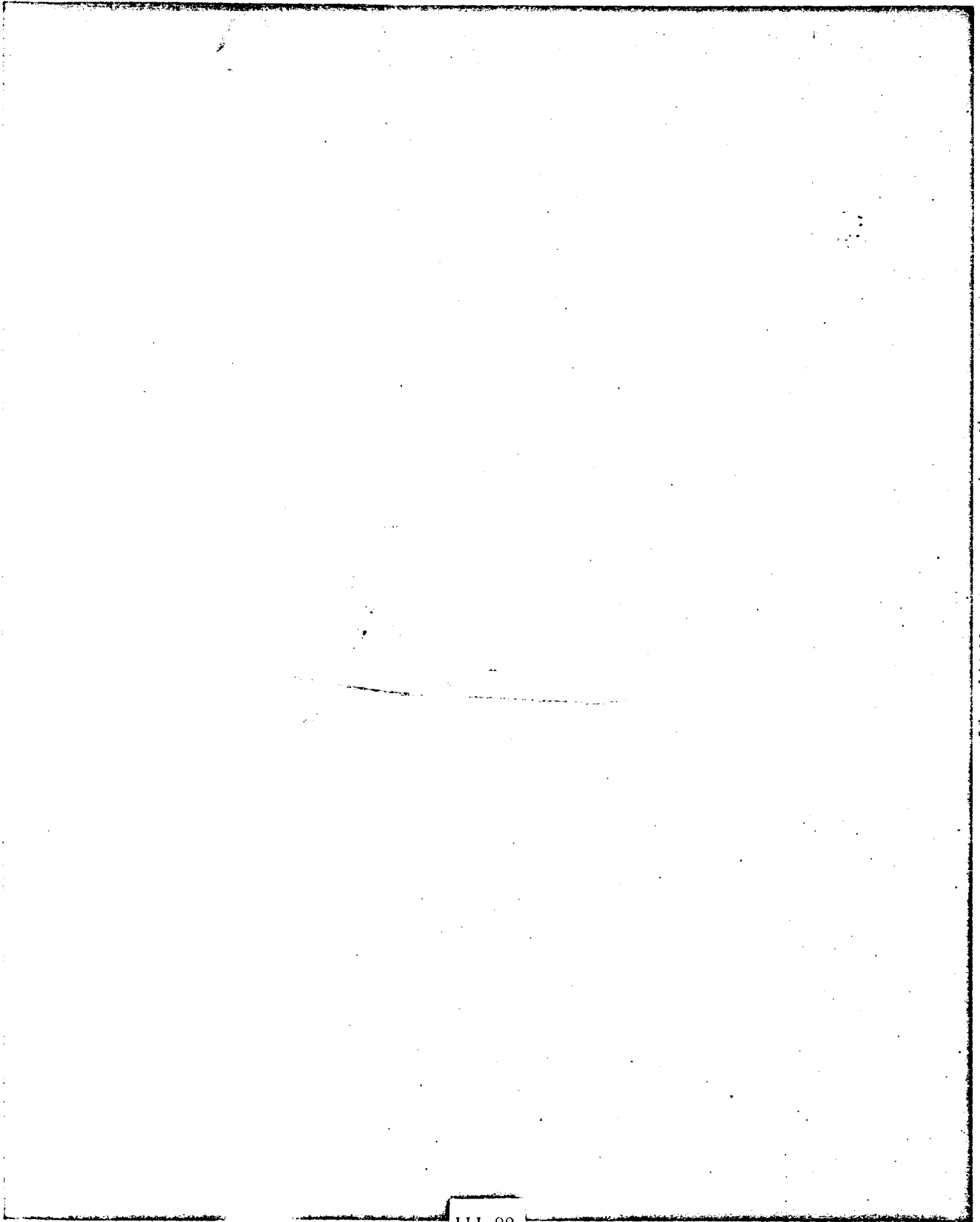


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AEROELASTICALLY CONFORMABLE ROTOR LOADS REDUCTION



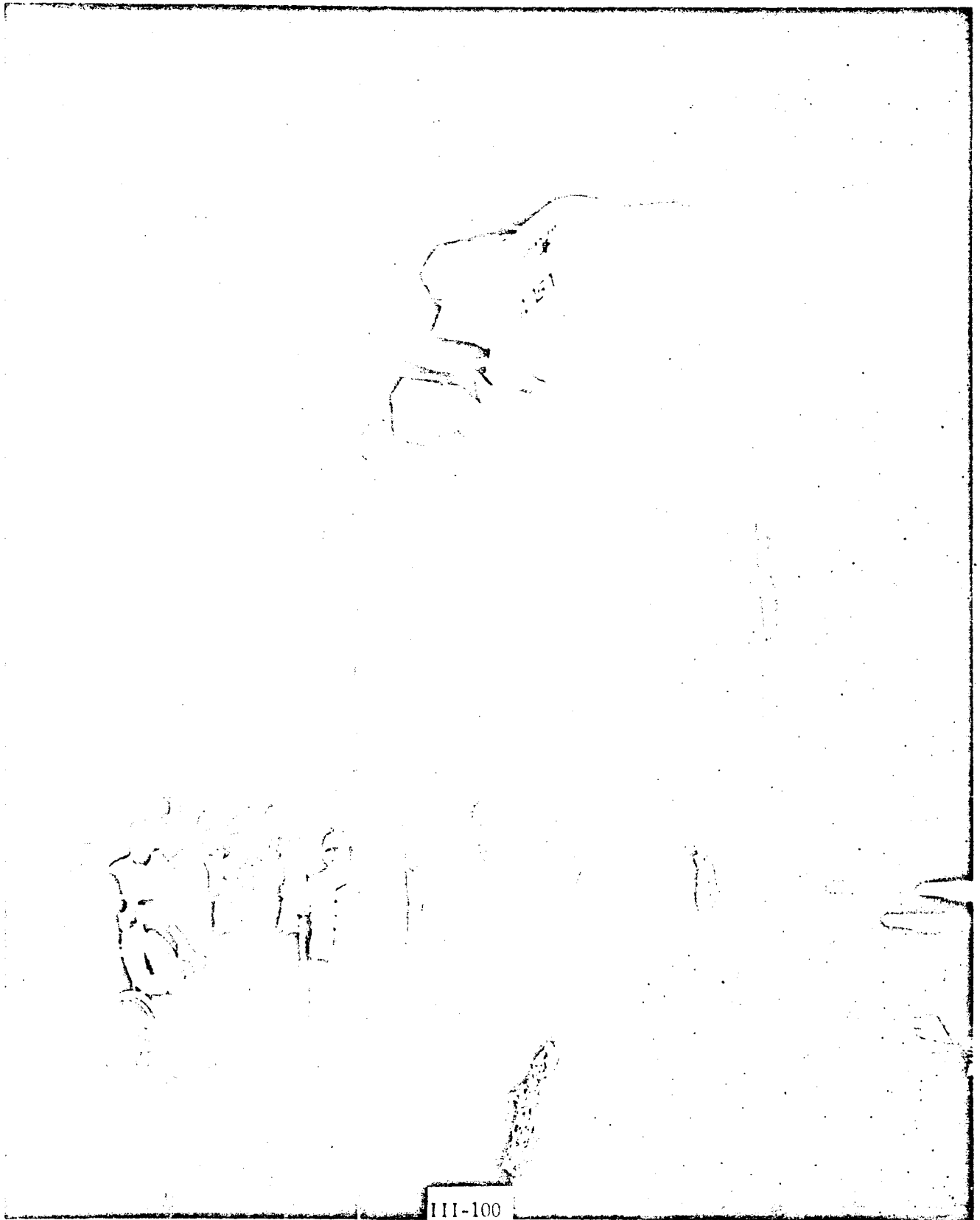
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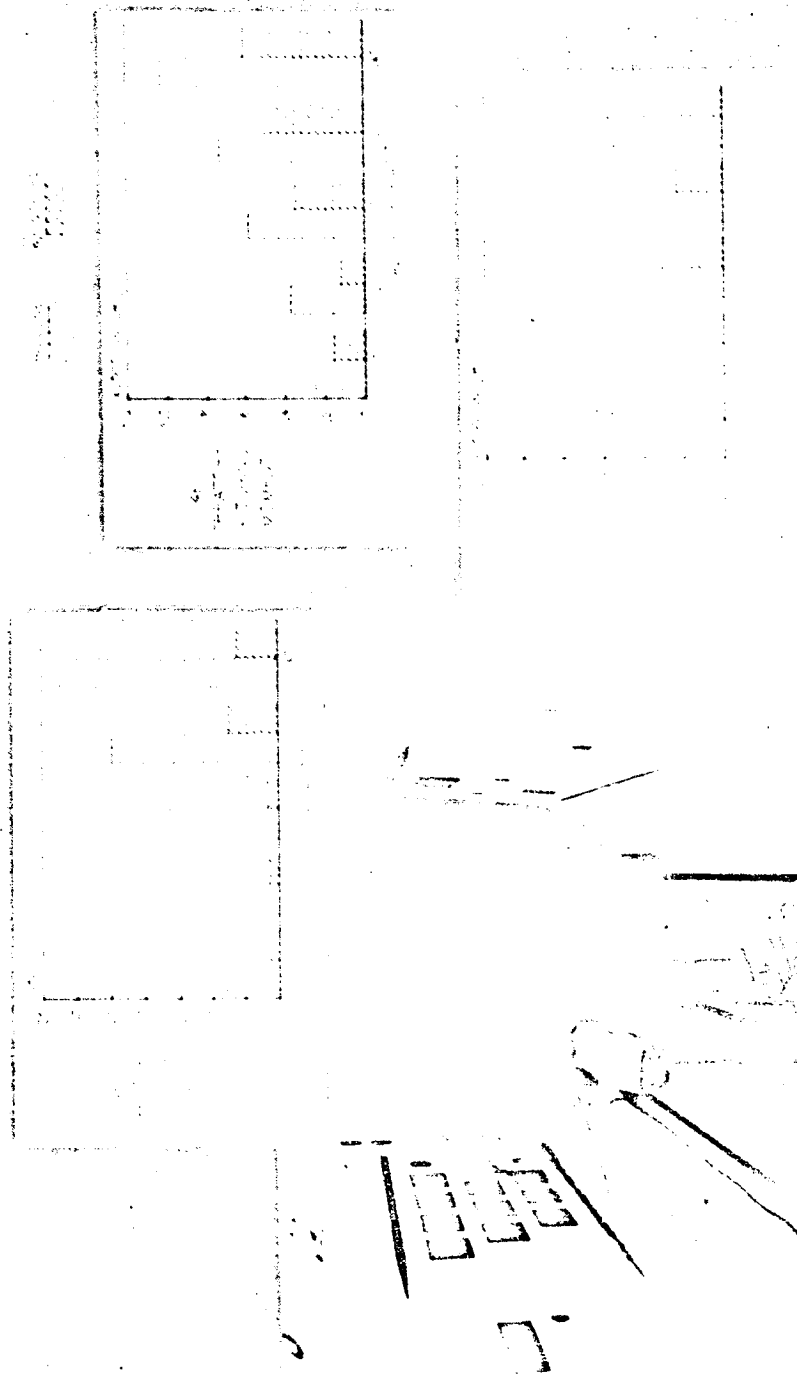
SEAPLANES: MAIN STATION (6 mi.) IN 40 x 20 TUNNEL

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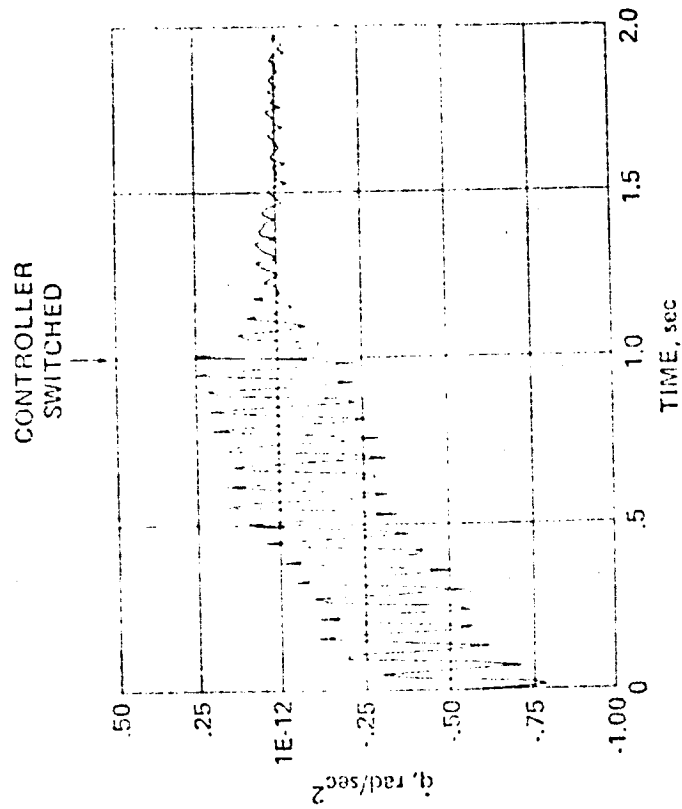
ADAPTIVE CONTROL SYSTEM FOR HELICOPTER V
REDUCTION SUCCESSFULLY TESTED



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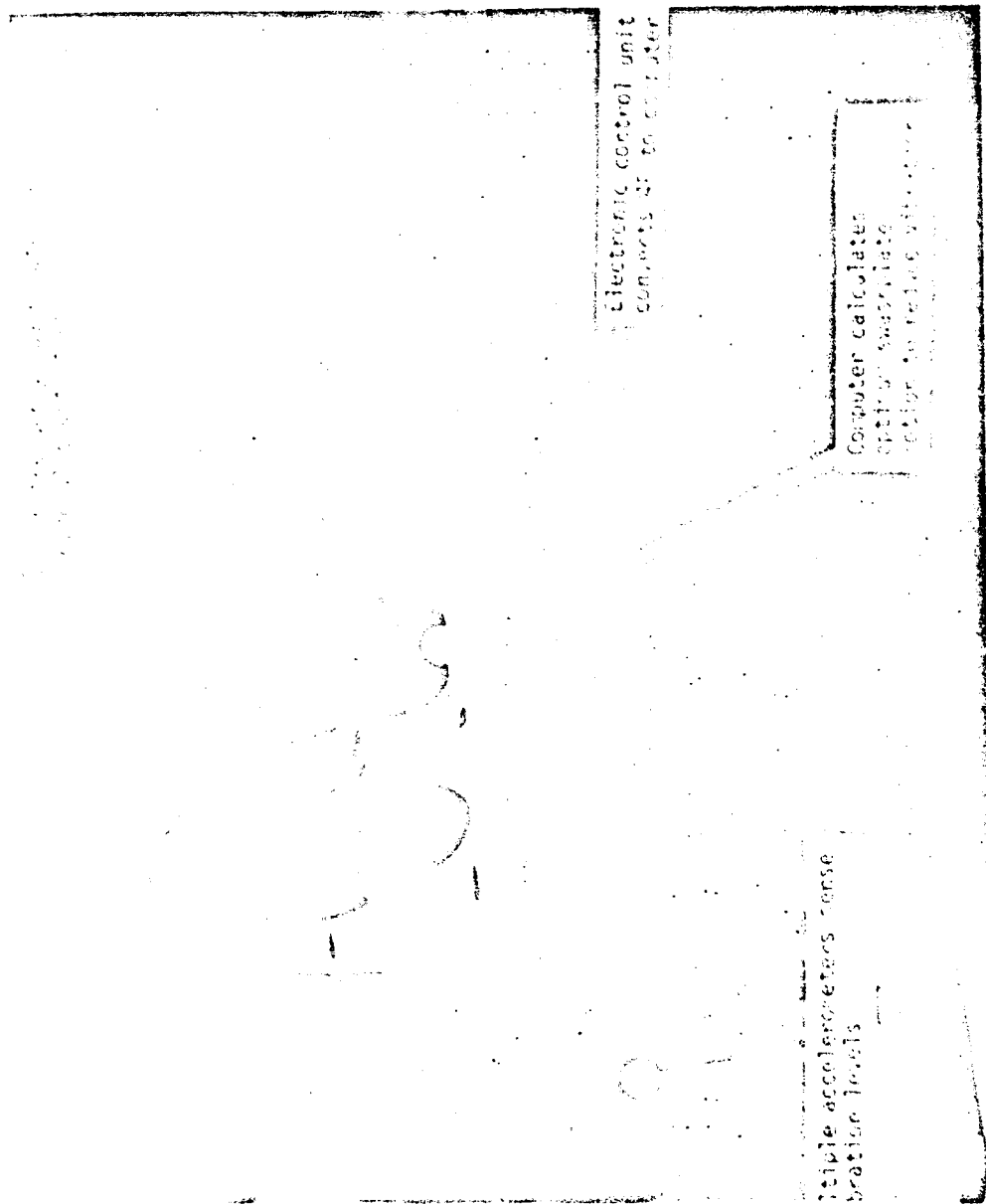
ACTIVE CONTROL OF ROTORCRAFT VIBRATIONS

PITCH ACCELERATION AT 120 knots
CONTROLLER DESIGNED FOR HOVER



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IMPLEMENTATION OF HIGHER HARMONIC CONTROL



ADVANCED VIBRATION SUPPRESSION ROTOR

OBJECTIVES:

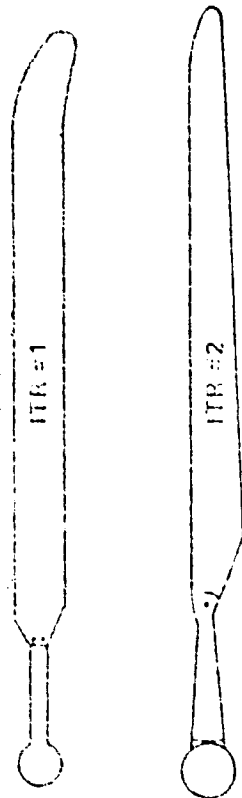
DEMONSTRATE RESEARCH ROTOR WITH INTEGRATED
CAPABILITIES OF HIGH CRUISE SPEED WITH QUIET,
EFFICIENT AND SMOOTH PERFORMANCE

PROCESS:

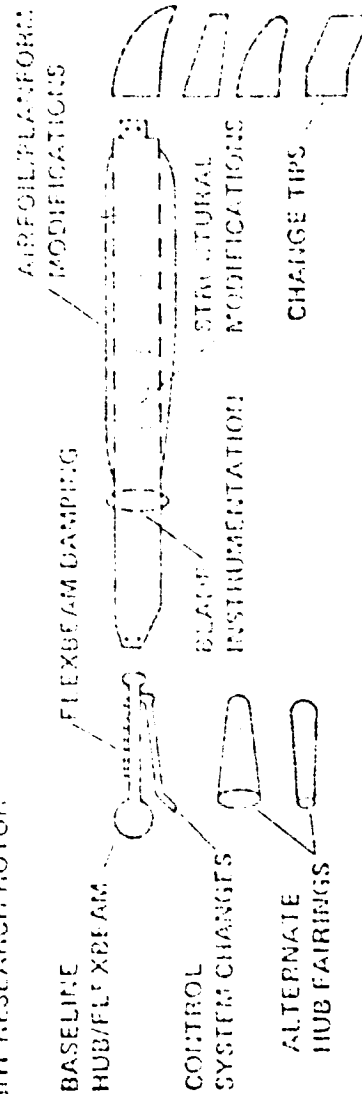
- o STUDIES TO IDENTIFY MOST PROMISING ROTOR CONCEPTS
- o DEVELOPMENT OF FLIGHT RESEARCH ROTOR
- o FLIGHT EXPERIMENTS ON ROTOR SYSTEMS RESEARCH AIRCRAFT
TO DEMONSTRATE CONCEPT

NASA/ARMY ATTACHED ROTORS PROJECT

BASELINE ROTORS



NASA FLIGHT RESEARCH ROTOR



ROTOR DEICING

OBJECTIVE: EVALUATE PERFORMANCE, EFFECTIVENESS, AND EFFICIENCY
OF ROTOR DEICING SYSTEMS

PROCESS: COMPONENT STUDIES AND TESTS
FLIGHT TESTS OF ALL-UP DEICING SYSTEM
ASSESSMENT OF ROTOR DEICING TECHNOLOGY
IDENTIFICATION OF CRITICAL SYSTEM NEEDS

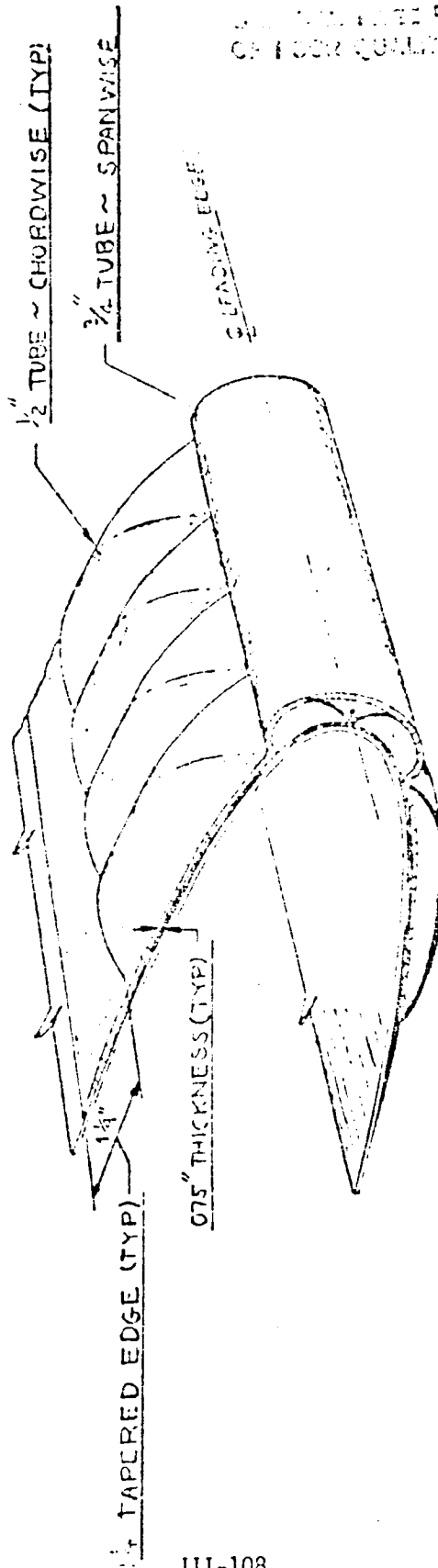
ROTOR BLADE DEICING

APPROACH

EVALUATE/VERIFY PNEUMATIC BOOT CONCEPT FOR ROTORS

CONCEPT PROPOSED - B. F. GOODRICH

- o COMPLETE SEMISPAN TEST IN NASA-LEWIS ICING TUNNEL: FEASIBILITY ESTABLISHED (1979)
- o 2D TESTS: BOOT AERODYNAMIC CHARACTERISTICS
- o LIFE CYCLE TESTS: ABRASION, FLEXURAL LIFE, AND MAINTENANCE.
- o EVALUATE CONCEPT USING NASA-AMES UH-1H



U.S. AIR FORCE
OF TROOP QUALITY

TYPICAL CROSS-SECTION OF INSTALLED DE-ICER (INFLATED)

SCALE: NONE

H. BENSON DEXTER
NASA LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

SUMMARY

The NASA Langley Research Center has been instrumental in the development of advanced composites technology during the past 15 years. The focus has been on commercial transport aircraft and the objective was to accelerate the development of advanced technologies to the point where manufacturers could economically incorporate the technology into their production aircraft. In the early 1970's NASA recognized the need to build confidence in the long-term durability of advanced composites. A series of flight service evaluation programs were initiated and almost 2 million successful component flight hours have been accumulated on over 140 composite components. In 1975 NASA initiated an extensive Aircraft Energy Efficiency (ACEE) program to improve the efficiency of commercial transport aircraft through the development and application of advanced technologies including advanced composites. Six components, three secondary structures, and three primary structures, are in the final stages of development. Confidence gained as a result of these programs aided Boeing in their decision to commit to advanced composite secondary structures on their model 757 and 767 aircraft.

Recently, NASA also started to focus attention on the development of advanced composites technology for helicopter airframe structures. Flight service evaluation programs have been initiated to develop a data base on the long-term durability of composites for helicopter structures. Over 150 Kevlar and graphite components will be evaluated on Bell 206L aircraft in varied environments including the Northeast United States, Canada, Alaska, and the Gulf Coast. The maintainability and reliability of the composite components will be tracked and tests will be conducted to determine residual strength as a function of service time. In addition, 15 composite components will be removed from several Sikorsky S-76 helicopters for testing after worldwide commercial service.

Ongoing NASA research programs are focusing on low-cost hybrid material concepts for improved structural efficiency, damage tolerance, and crashworthiness. Included are studies on minimum gage hybrid buckled-skin fuselage concepts and composite material concepts for improved energy absorption characteristics for use in fuselage floor structure for improved safety and crashworthiness. A study is underway to examine advanced structural material concepts for the next generation helicopter fuselage. The objectives are to establish advanced design philosophy to achieve maximum benefits of composites, conduct trade studies to arrive at structurally efficient designs, conduct fabrication feasibility studies, and perform a cost and weight comparison of composite structure with metal baseline structure.

A new program is being planned by NASA for an advanced composite helicopter airframe technology development program for primary structures. The NASA program would follow the U.S. Army Advanced Composite Airframe Program (ACAP) and would focus on technology beyond the current state-of-the-art. Included in this program will be the development of aggressive design and fabrication techniques, improved analytical capabilities to predict structural response, and improved damage tolerance and crashworthiness. This advanced technology will be demonstrated through design, fabrication, and test of full-scale primary helicopter structures. Tests will include static, fatigue, vibration and dynamic impact. The capability to predict static and dynamic structural response will be verified. As a result of this advanced technology the helicopter manufacturers will be in a position to commit to advanced composite primary airframe structures for the next generation helicopters. Benefits expected include, reduced fuel consumption, improved productivity, improved reliability and maintainability, and lower life cycle costs to the operators.

COMPOSITE AIRFRAME

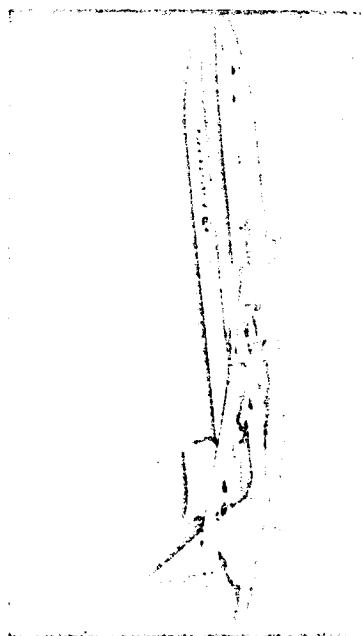
MAJOR TASKS	DESCRIPTION	CONTACTS/RTOP
1. Flight service evaluation of composite components on helicopters. (ongoing program)	Programs are currently underway to evaluate the behavior of advanced composite components in realistic operational helicopter environments. The objectives of these programs are to establish confidence in the long-term durability of composite materials, provide a data base on maintainability, and to determine residual strength of composite components as a function of service time.	B. Dexter/Materials Processing and Applications Br./LaRC/2869/505-42-13
2. Evaluation of low-cost hybrid materials concepts. (ongoing program)	Studies are underway to investigate low-cost material concepts for helicopter fuselage structure. The objectives are to establish structurally efficient concepts including Kevlar/graphite hybrid fuselage panels and graphite/epoxy transmission support structure.	B. Dexter/Materials Processing and Applications Br./LaRC/2869/505-42-13
3. Investigation of composite concepts for improved energy absorption and crashworthiness. (ongoing program)	Experimental studies are underway to understand the energy absorption characteristics of composite materials. The objective is to develop composite design concepts that will lead to improved safety and crashworthiness in potential crash conditions.	B. Dexter/Materials Processing and Applications Br./LaRC/2869/532-06-13

COMPOSITE AIRFRAME

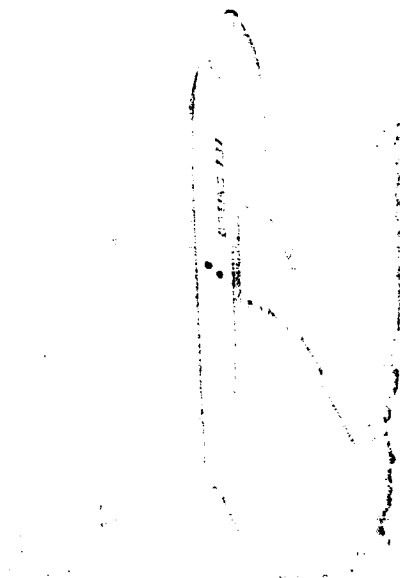
MAJOR TASKS	DESCRIPTION	CONTACTS/RTOP
<p>4. Study of advanced structural material concepts for the next generation helicopter fuselage. (ongoing program)</p>	<p>A design study is being initiated to investigate advanced materials concepts for future helicopter fuselage structures. Advanced design philosophy will be used and design tradeoff studies will be conducted. A study of innovative fabrication concepts will be performed and cost and weight comparisons will be made.</p>	<p>B. Dexter/Materials Processing and Applications Br./LaRC/2869/532-06-13</p>
<p>5. Develop advanced composite airframe technology. (proposed program)</p>	<p>A new initiative is being planned to develop advanced composite airframe technology for primary structures that are beyond the current state-of-the-art. Aggressive design and fabrication techniques will be developed. Improved analytical capabilities to predict static and dynamic structural response will be developed. Design of joints and splices will be optimized and concepts for improved damage tolerance will be developed.</p>	<p>B. Dexter/Materials Processing and Applications Br./LaRC/2869/532-06-13</p>
<p>6. Demonstrate advanced composite airframe technology. (proposed program)</p>	<p>The second phase of the new initiative will demonstrate advanced composite airframe technology through design, fabrication, and test of full-scale primary structures. Tests will include static, fatigue, vibration, and dynamic impact. The capability to predict structural response will be verified.</p>	<p>B. Dexter/Materials Processing and Applications Br./LaRC/2869/532-06-13</p>

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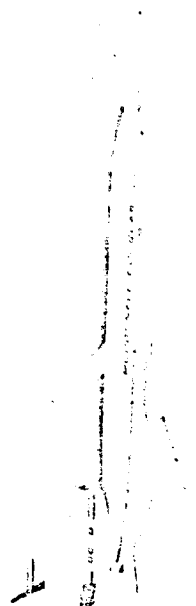
FLIGHT SERVICE COMPONENTS
ON TRANSPORT AIRCRAFT



L-1011 FAIRING



B-737 SPOILER



DC-10 RUDDER AND AFT PYLON



C-130 WING BOX

NASA COMPOSITE STRUCTURES FLIGHT SERVICE SUMMARY

AIRCRAFT, COMPONENT	TOTAL COMPONENTS	START OF FLIGHT SERVICE	CUMULATIVE FLIGHT HOURS	
			HIGH TIME AIRCRAFT	TOTAL COMPONENT
CH-54B TAIL CONE	1	MARCH 1972	1,140	1,140
L-1011 FAIRING PANELS	18	JANUARY 1973	18,352	320,150
737 SPOILER	108	JULY 1973	19,947	1,482,550
C-130 CENTER WING BOX	2	OCTOBER 1974	4,666	9,280
DC-10 AFT PYLON, SKIN	3	AUGUST 1975	14,804	44,110
DC-10 UPPER AFT RUDDER	12*	APRIL 1976	17,689	124,700
GRAND TOTAL	144			1,981,930

*EIGHT MORE RUDDERS TO BE INSTALLED

OCTOBER, 1980

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[ACEE]

COMPOSITE
SECONDARY
STRUCTURES

DOUGLAS DC-10 COMPOSITE RUDDER

DOUGLAS DC-10 COMPOSITE RUDDER

LOCKHEED L-1011 COMPOSITEAILERON

ACEE
COMPOSITE
PRIMARY
STRUCTURES

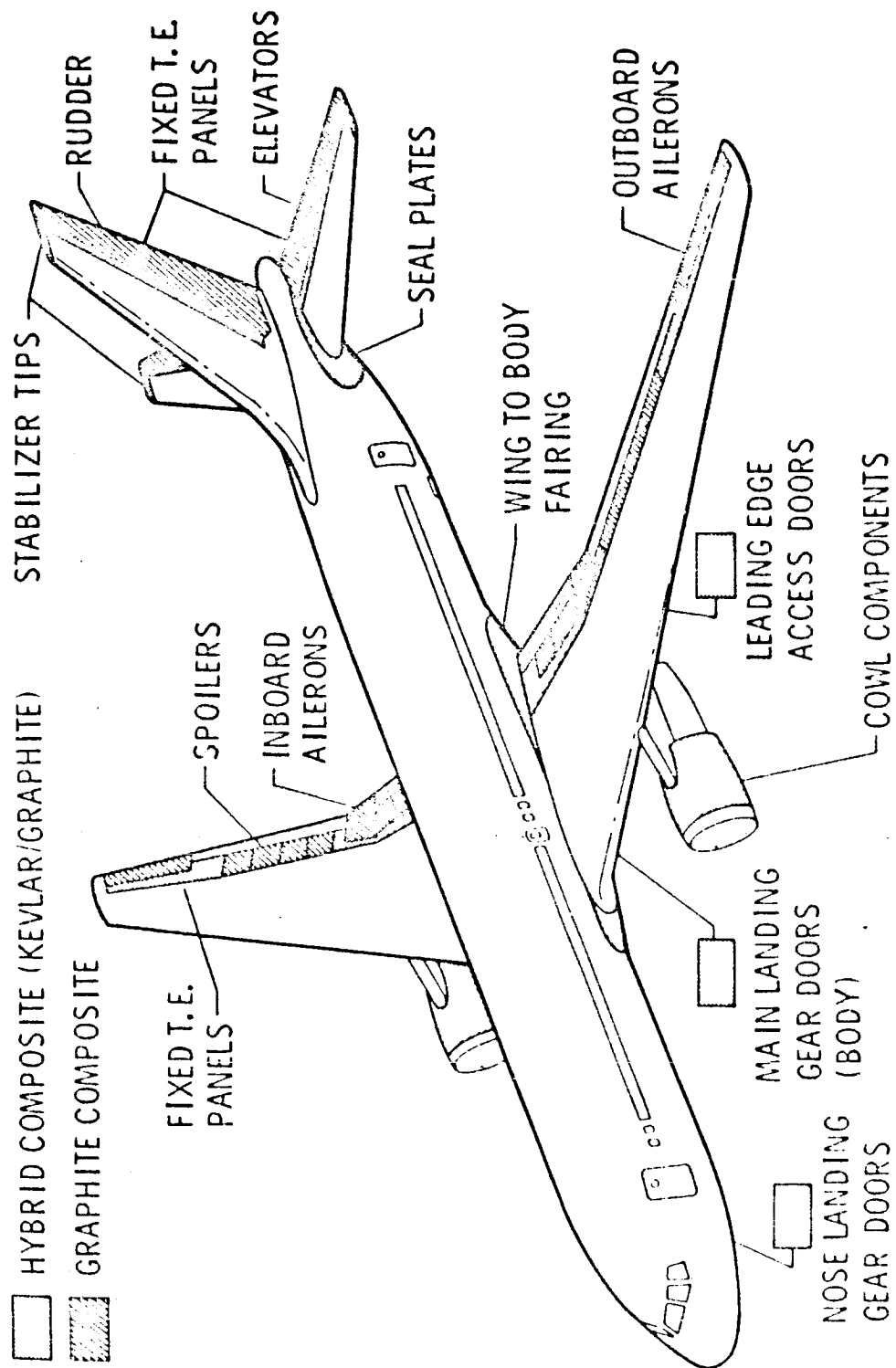
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BOEING 737 COMPOSITE HORIZONTAL STABILIZER

LOCKHEED L-1011 COMPOSITE VERTICAL FIN

DOUGLAS DC-10 COMPOSITE VERTICAL STABILIZER

BOEING 767 COMPOSITE STRUCTURE APPLICATIONS



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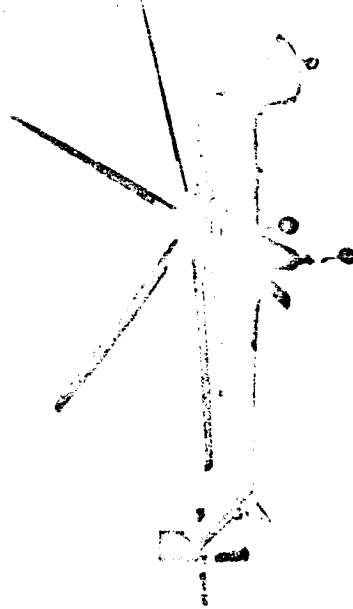
FLIGHT SERVICE COMPOSITE COMPONENTS ON HELICOPTERS



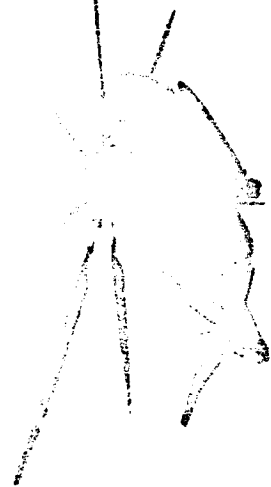
203L DOORS, FAIRING AND
VERTICAL FIN



S-76 TAIL ROTOR AND
HORIZONTAL FIN



CH-54 FUSELAGE



CH-53 CARGO RAMP SKIN

OBJECTIVES OF COMPOSITE FLIGHT SERVICE EVALUATION PROGRAMS

- o MANUFACTURE MULTIPLE COMPONENTS IN A NEAR PRODUCTION ENVIRONMENT.
- o OBTAIN FAA CERTIFICATION OF FLIGHTWORTHY COMPOSITE COMPONENTS.
- o ESTABLISH A DATA BASE ON THE MAINTAINABILITY OF COMPOSITE STRUCTURES.
- o DEVELOP CONFIDENCE IN THE LONG-TERM DURABILITY OF COMPOSITE STRUCTURES.
- o DETERMINE RESIDUAL STRENGTH OF COMPOSITE COMPONENTS AS A FUNCTION OF SERVICE TIME.

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LEFT SIDE ELEVATION OF PARTIAL C

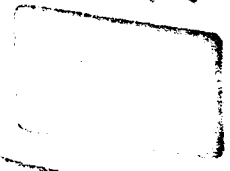


FORWARD FAIRING
KEVLAR/EPOXY FABRIC
STIFFENED FOAM SANDWICH
MASS (kg) 2.31
SIZE (m) 0.50 x 0.74

VERTICAL FIN
GRAPHTER/EPOXY TAPE
FIBER TRUSS CORE
MASS (kg) 5.53
SIZE (m) 1.53 x 0.59

2

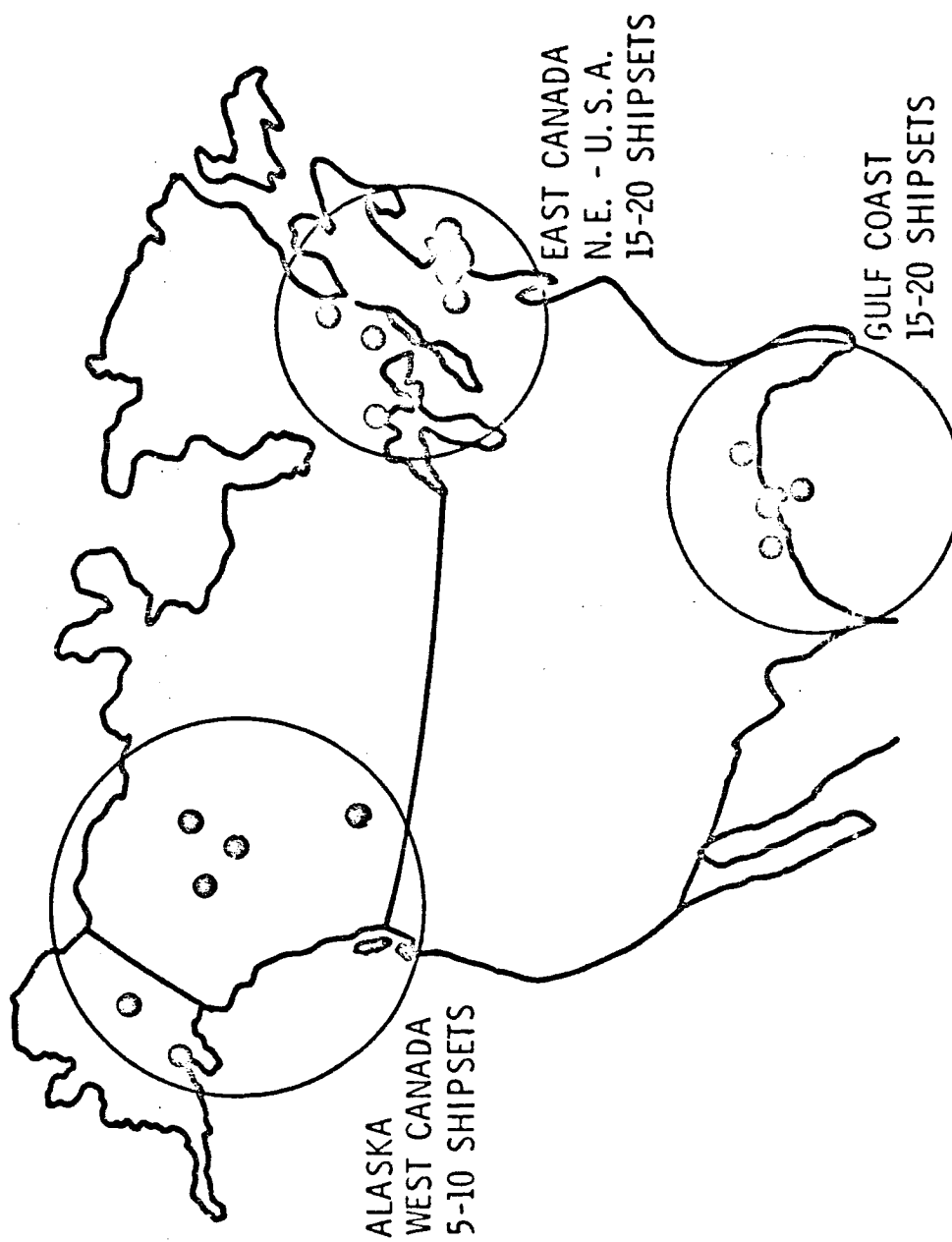
6182



LITTER DOOR
KEVLAR/EPOXY FABRIC
TWO SKINS - HOLLOW SECTION
MASS (kg) 3.72
SIZE (m) 1.17 x 0.66

BAGGAGE DOOR
KEVLAR/EPOXY FABRIC
HONEYCOMB SANDWICH
MASS (kg) 1.41
SIZE (m) 0.97 x 0.58

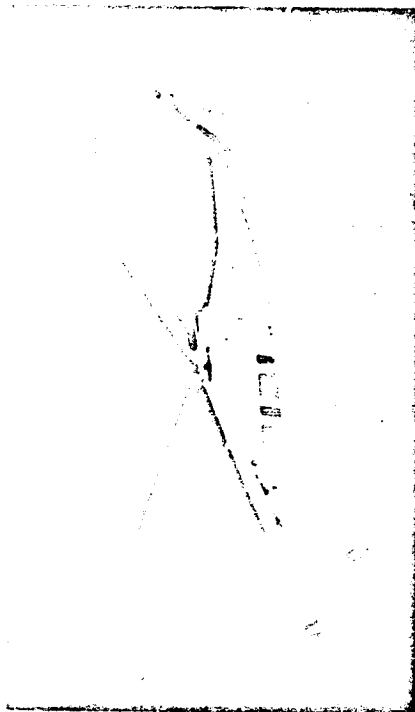
DISTRIBUTION OF DELL 20CL COMPONENTS



POTENTIAL OPERATORS TO EVALUATE COMPOSITE COMPONENTS ON BELL 206L HELICOPTERS

<u>OPERATOR</u>	<u>LOCATION</u>
TRANSPORT CANADA	N.E. U.S./CANADA
HELI-VOYAGER	N.E. U.S./CANADA
HUISSON AVIATION LTD.	N.E. U.S./CANADA
ROYAL CAN. MTD. POLICE	N.E. U.S./CANADA
TRANS. QUEBEC LTD.	N.E. U.S./CANADA
TRANS. CANADA HELICOPTERS	N.E. U.S./CANADA
RONSON AVIATION	N.E. U.S.
INTERPACE CORP.	NEW JERSEY
ISLAND HELICOPTER CORP.	NEWFOUNDLAND & LABRADOR
ERA HELICOPTERS, INC.	ALASKA
KENAI AIR ALASKA, INC.	ALASKA
MOBIL OIL CORP.	GULF COAST
BLED SOE AVIATION, INC.	GULF COAST
PETROLEUM HELICOPTERS, INC.	GULF COAST

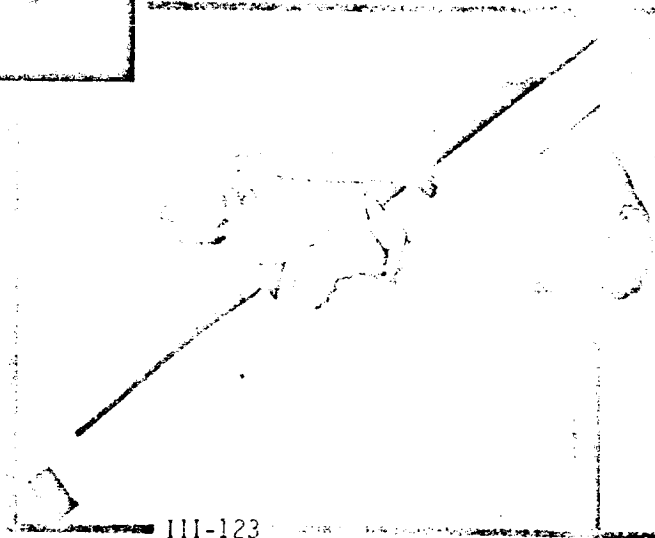
COPIES OF THE



- GNAPHITE EPOXY SPAR
- GLASS EPOXY SKIN
- WEIGHT [kg] 66
- SIZE [mm] 24 x 2

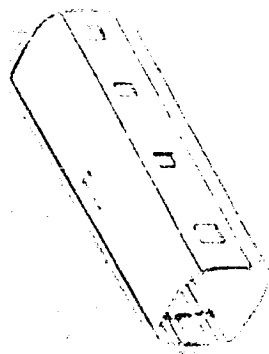
HORIZONTAL STABILIZER

- GRAPHITE Kevlar Epoxy Spar
- Kevlar Epoxy Skin
- Nomex Honeycomb Sandwich
- Weight (kg) 181
- Size (m) 2.9 x 8

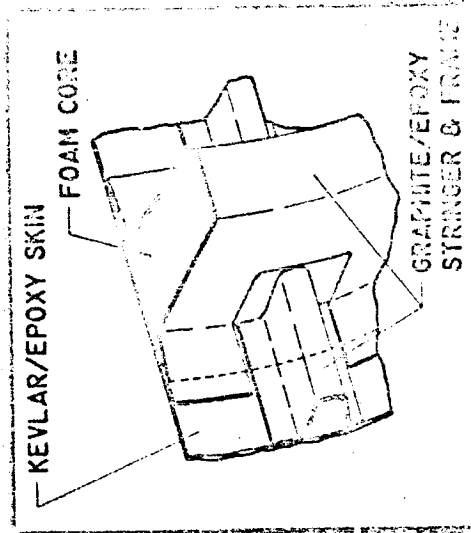


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COMPONENT: STRUCTURAL



FUSelage SECTION

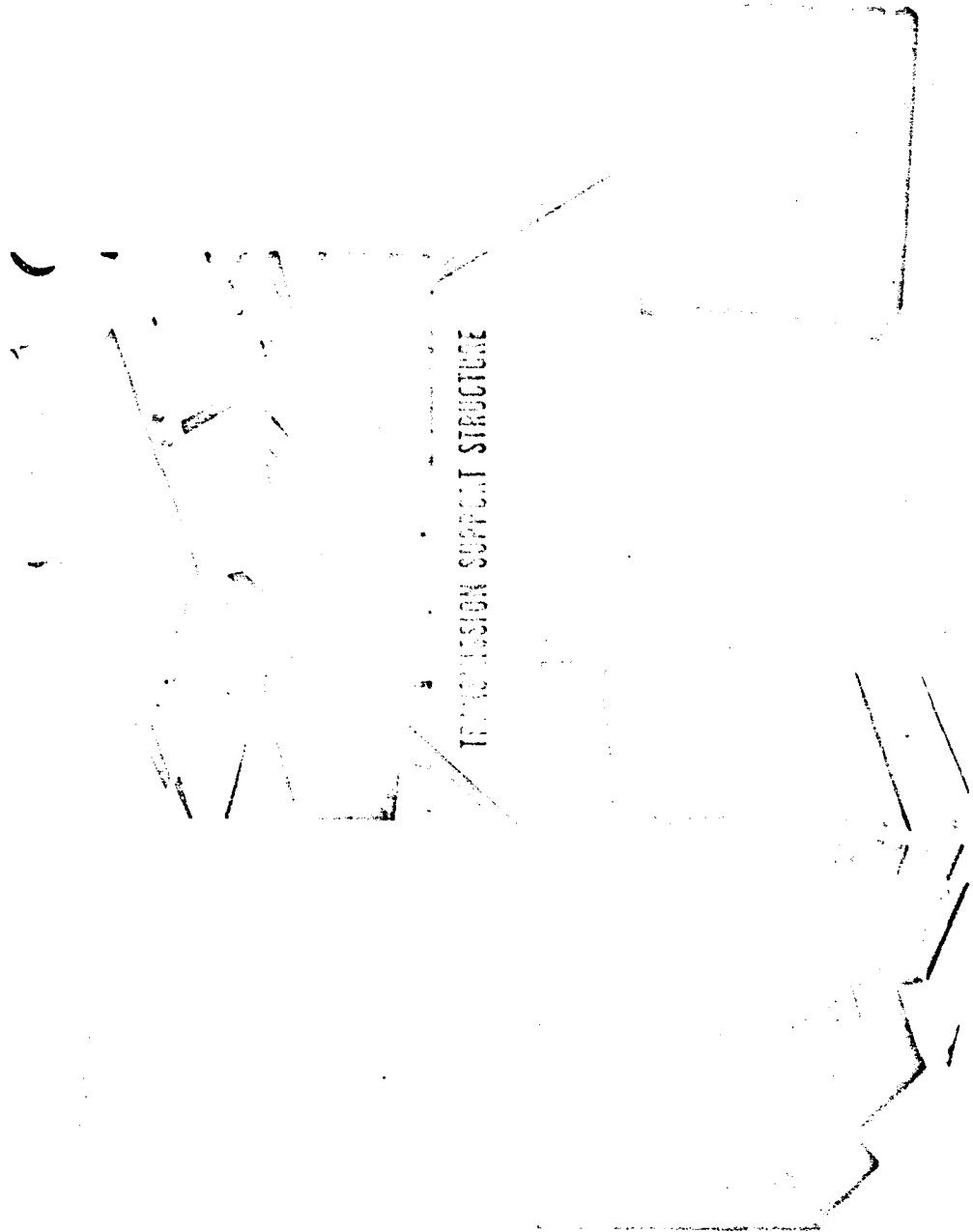


CONSTRUCTION DETAILS

TYPICAL PANEL

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DESIGN FACILITATION AND TEST OF HELICOPTER TRANSMISSION STRUCTURE



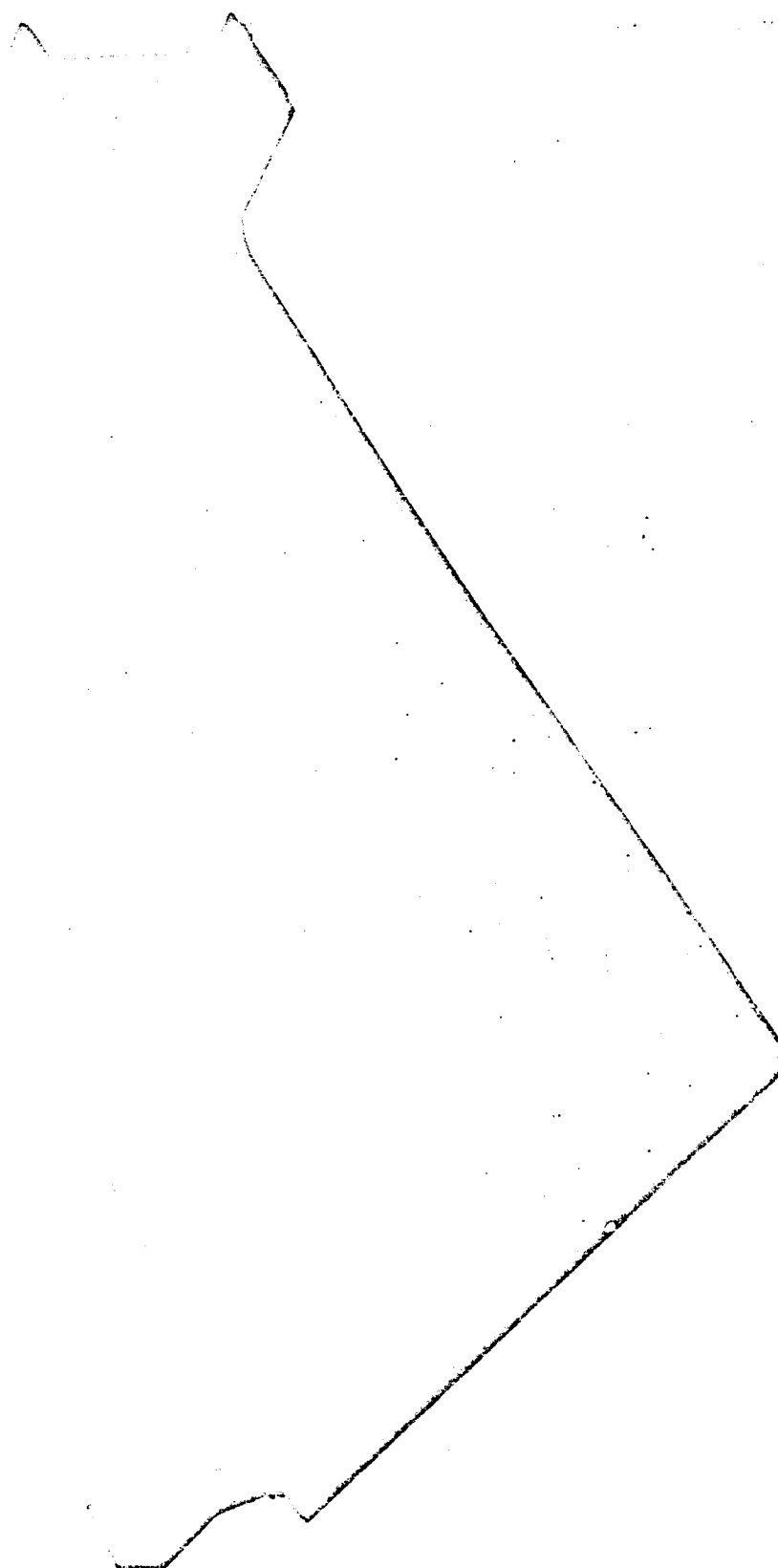
TRANSMISSION SUPPORT STRUCTURE

BEAM FRAME INTERSECTION

TRANSMISSION ATTACH FITTING

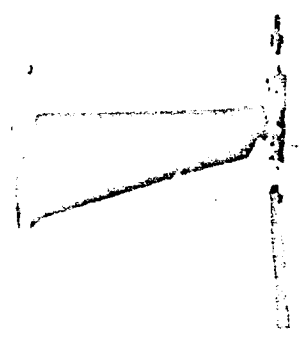
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GRAPHITE/EPOXY HELICOPTER TRANSMISSION SUPPORT STRUCTURE



111-126

S-76 COMPOSITE APPLICATIONS



TITANIUM, FIBERGLASS,
GRAPHITE, NOMEX HONEYCOMB



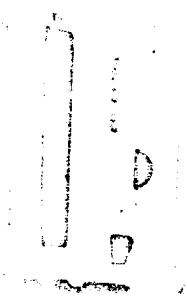
GRAPHITE



GRAPHITE, FIBERGLASS



KELVAR, CARBONITE,
FIBERGLASS,
ALUMINUM HONEYCOMB



KELVAR, CARBONITE

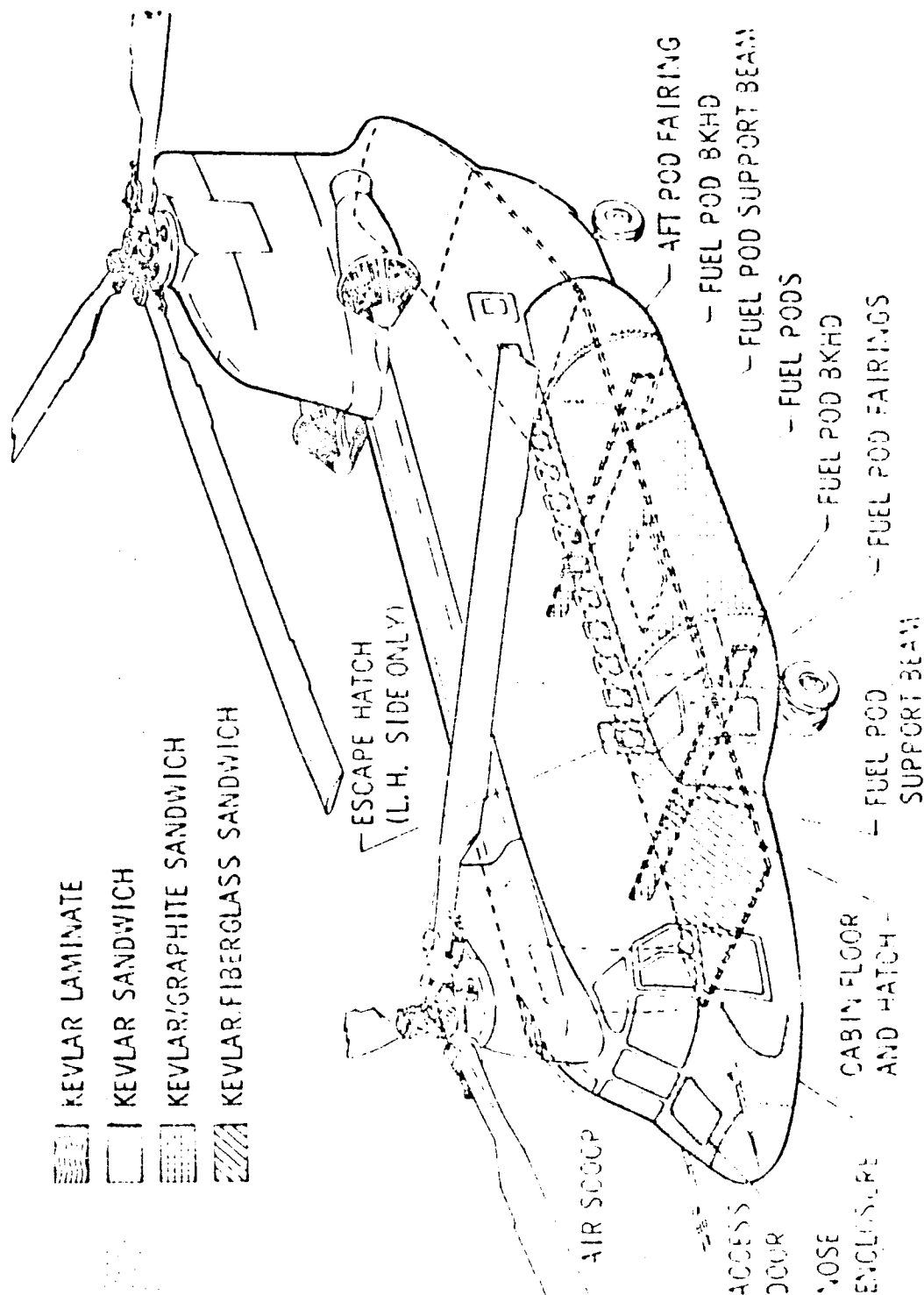


KELVAR, CARBONITE



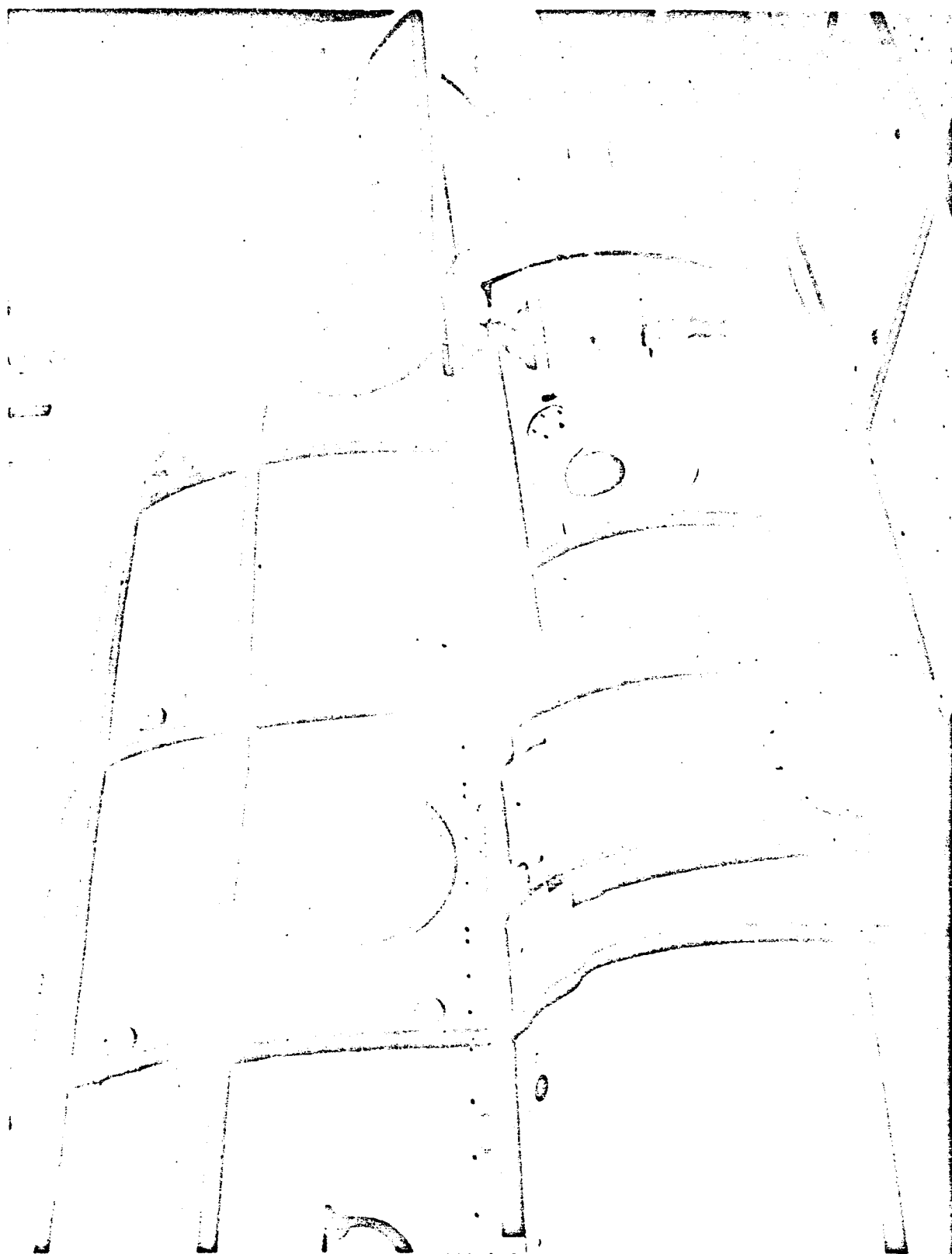
KELVAR, CARBONITE

BOEING 234 HELICOPTER COMPOSITE APPLICATIONS



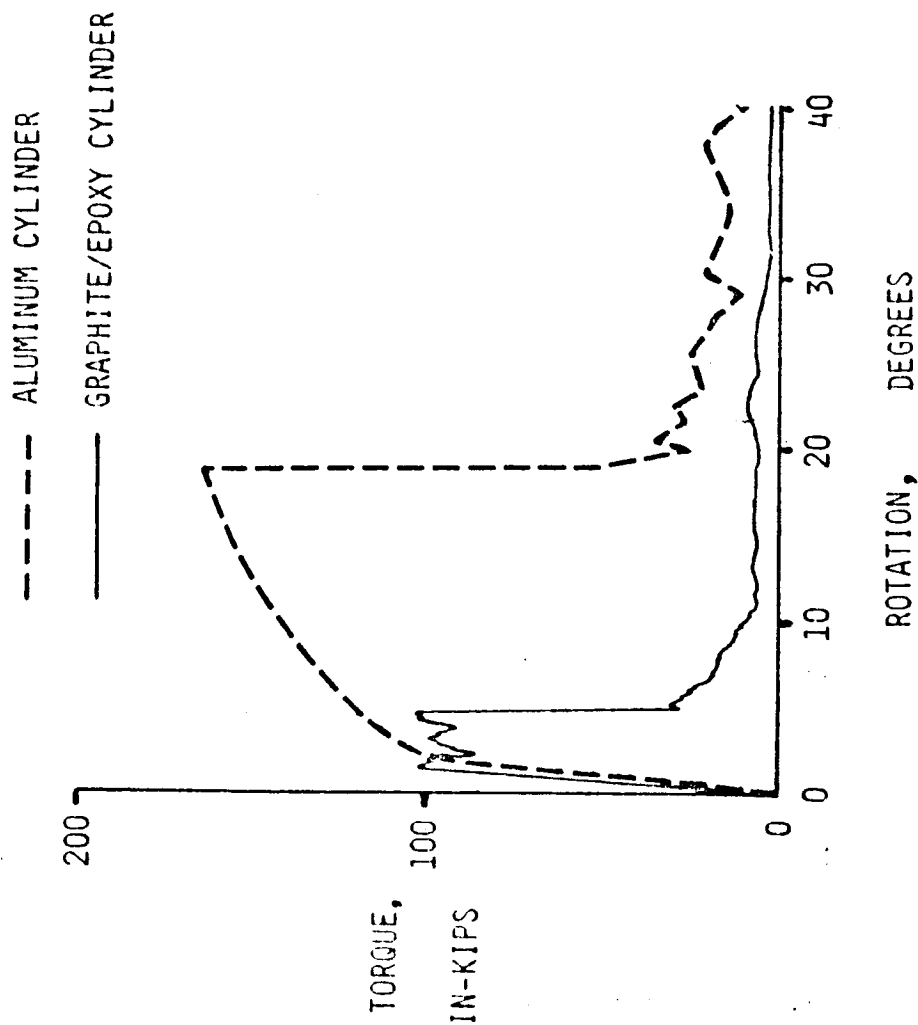
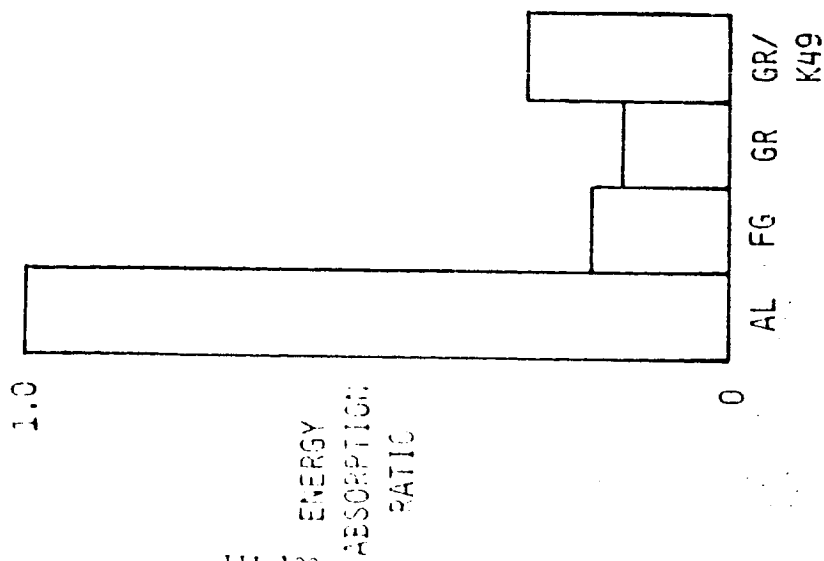
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CRASH TEST OF CH-47 HELICOPTER



111-129

ENERGY ABSORPTION OF COMPOSITE AND ALUMINUM HONEYCOMB STIFFENED CYLINDERS

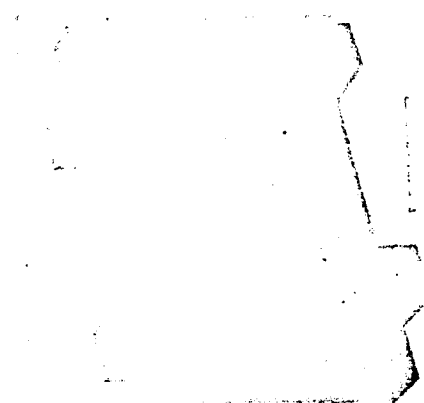


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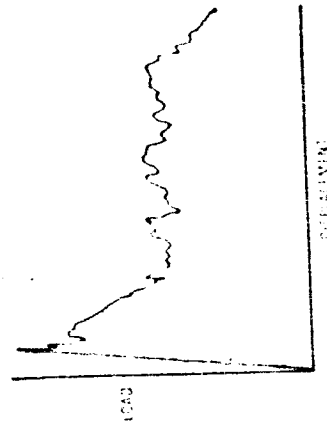
ENERGY ABSORPTION OF KEVLAR/EPOXY HONEYCOMB SANDWICH BEAM



AFTER TEST



BEFORE TEST



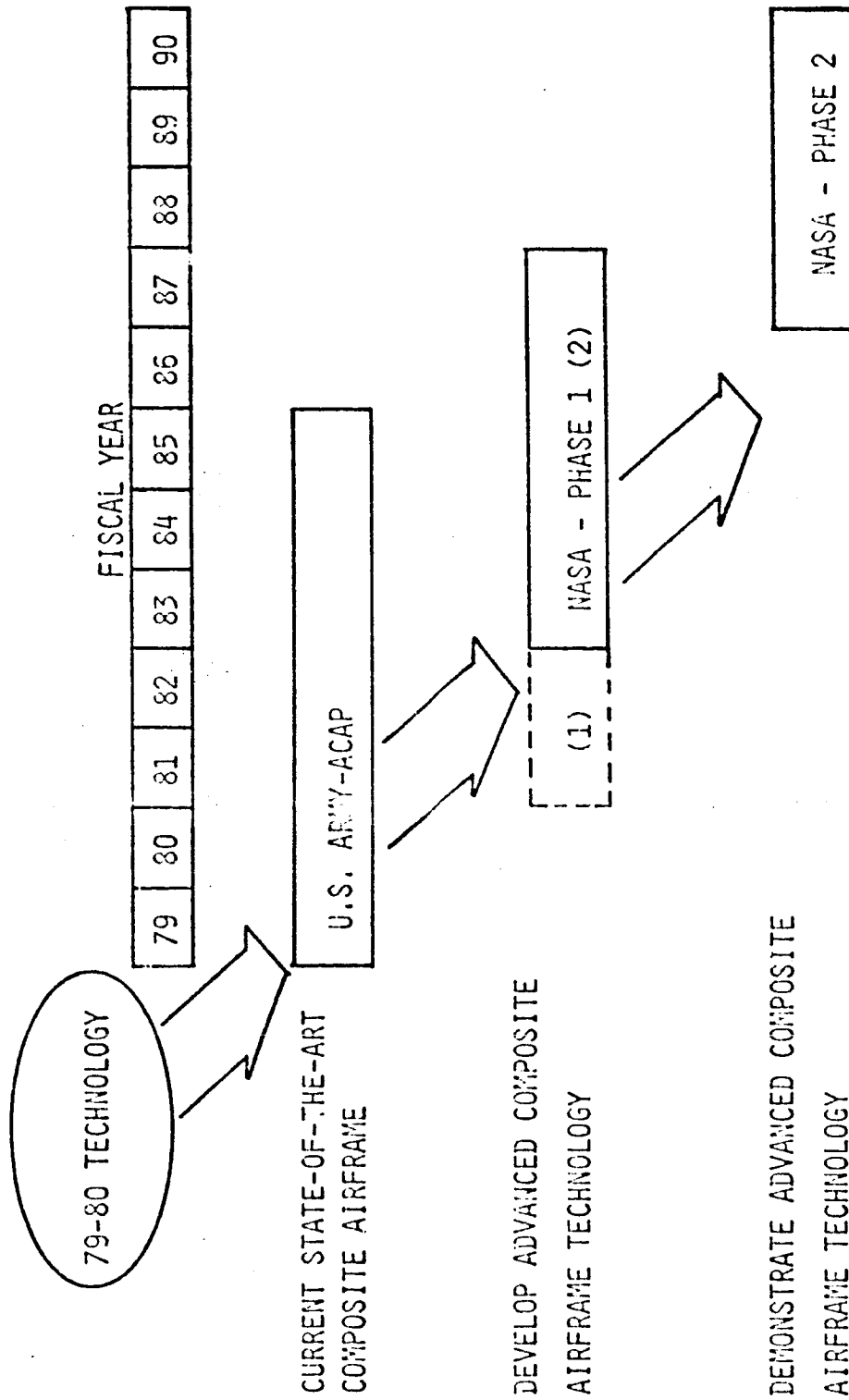
LOAD-DISPLACEMENT

ADVANCED STRUCTURAL MATERIALS CONCEPTS FOR THE NEXT GENERATION HELICOPTER FUSELAGE

OBJECTIVES

- o ESTABLISH ADVANCED DESIGN PHILOSOPHY TO ACHIEVE MAXIMUM BENEFIT OF COMPOSITE MATERIALS.
- o CONDUCT DESIGN TRADEOFF STUDIES ON VARIOUS MATERIAL COMBINATIONS AND CONCEPTS TO ARRIVE AT STRUCTURALLY EFFICIENT DESIGNS.
- o CONDUCT FABRICATION FEASIBILITY STUDIES.
- o PERFORM COST AND WEIGHT COMPARISON WITH BASELINE METAL STRUCTURE.

COMPOSITE HELICOPTER AIRFRAME PROGRAMS



NASA COMPOSITE HELICOPTER AIRFRAME PROGRAM

-PROPOSED FY 1983 NEW INITIATIVE-

0 DEVELOP ADVANCED COMPOSITE AIRFRAME TECHNOLOGY

- AGGRESSIVE DESIGN AND FABRICATION TECHNIQUES.
- IMPROVED ANALYTICAL CAPABILITIES TO PREDICT STATIC AND DYNAMIC STRUCTURAL RESPONSE.
- CONCEPTS FOR IMPROVED DAMAGE TOLERANCE AND CRASHWORTHINESS.

0 DEMONSTRATE ADVANCED COMPOSITE AIRFRAME TECHNOLOGY

- DESIGN AND FABRICATE FULL-SCALE PRIMARY STRUCTURES.
- CONDUCT STATIC, FATIGUE, VIBRATION AND DYNAMIC IMPACT TESTS.
- VERIFY CAPABILITY TO PREDICT STATIC AND DYNAMIC STRUCTURAL RESPONSE.

CONCLUDING REMARKS

- o ADVANCED COMPOSITES TECHNOLOGY HAS BEEN DEVELOPED TO THE POINT WHERE MANUFACTURERS ARE MAKING PRODUCTION COMMITMENTS TO COMPOSITES FOR SELECTED COMPONENTS.
- o NASA SPONSORED FLIGHT SERVICE EVALUATION PROGRAMS WILL ESTABLISH CONFIDENCE IN THE LONG-TERM DURABILITY OF COMPOSITE HELICOPTER STRUCTURES.
- o ONGOING NASA PROGRAMS ARE FOCUSING ON LOW-COST HYBRID MATERIAL CONCEPTS FOR IMPROVED STRUCTURAL EFFICIENCY, DAMAGE TOLERANCE, AND CRASHWORTHINESS.
- o PLANS ARE BEING FORMULATED TO INITIATE AN ADVANCED COMPOSITE HELICOPTER AIRFRAME TECHNOLOGY PROGRAM FOR PRIMARY STRUCTURES THAT ARE BEYOND THE CURRENT STATE-OF-THE-ART.

Performance Panel

Chairman and Keynote

- William Walls
Boeing Vertol

NASA Representative

Wayne Johnson
Ames

James Rorke

- Hughes

Troy Gaffey

- Bell

Jack Landgrege

- United Technologies
Research

Discussion

HAA/NASA ADVANCED ROTORCRAFT TECHNOLOGY WORKSHOP

AERODYNAMICS PANEL SESSION

ABSTRACT OF KEYNOTE ADDRESS BY W. W. WALLS

OPERATORS AND USERS OF HELICOPTERS WILL MEASURE THE USEFULNESS OF MUCH OF AERODYNAMICS RESEARCH BY THE IMPACT IT HAS ON OPERATING COST. FUEL COST IS A MAJOR ELEMENT IN OPERATING COST AND WE ALL KNOW VERY WELL THAT FUEL COSTS HAVE BEEN RISING RAPIDLY. PREDICTING THE COST OF FUEL FOR THE MID 1980'S IS IMPOSSIBLE. CONSERVATIVE ESTIMATES OF \$2.00 TO \$2.50 PER GALLON WOULD DOUBLE TODAY'S FUEL COST.

IMPACT OF FUEL COST - CHART #1

FUEL COSTS WERE 13% OF OPERATING COSTS IN 1978. IN 1979 FUEL REPRESENTED 18% OF OPERATING COSTS AND THIS YEAR IT IS 29%. FUEL COSTS HAVE RISEN AT A MUCH MORE RAPID RATE THAN LABOR, PARTS OR OPERATOR'S FIXED COSTS.

FUEL EFFICIENCY - CHART #2

IMPROVED FUEL EFFICIENCY FOR HELICOPTERS WILL NOT COME ONLY FROM AERODYNAMIC IMPROVEMENTS. LIGHTER WEIGHT STRUCTURE, ADVANCED ENGINES AS WELL AS REDUCED DRAG LEVELS AND MORE EFFICIENT ROTORS WILL CONTRIBUTE TO ACHIEVING IMPROVED FUEL EFFICIENCY.

WEIGHT EMPTY - CHART #3

THE WEIGHT EMPTY TO GROSS WEIGHT FRACTION HAS REDUCED FROM 70% TO 50% IN THE PAST TWO DECADES. THIS IMPROVEMENT DERIVED FROM THE INCORPORATION OF THE TURBINE ENGINES AND THE USE OF HIGH STRENGTH STEEL AND ALUMINUM ALLOYS, TITANIUM AND COMPOSITE MATERIALS. THE FUTURE WILL SEE APPLICATIONS OF EVEN HIGHER STRENGTH STEEL AND ALUMINUM ALLOYS, WIDER APPLICATION OF COMPOSITES IN PRIMARY STRUCTURE AND DRIVE SYSTEMS, MULTIPLEXING, INTEGRATED DISPLAYS AND FLY BY OPTICS - MANY OF THESE ADVANCES HAVE BEEN PROVEN IN THE LABORATORY AND NEED ONLY TO BE VERIFIED BY FULL SCALE APPLICATION. BY THE 1990'S, NEW HELICOPTERS WITH THESE FEATURES CAN HAVE A WEIGHT EMPTY FRACTION OF 40%. THIS TWENTY PERCENT REDUCTION IN WEIGHT EMPTY WOULD PRODUCE A SIX PERCENT GAIN IN FUEL EFFICIENCY.

ENGINE FUEL CONSUMPTION - CHART #4

SUBSTANTIAL IMPROVEMENTS IN SPECIFIC FUEL CONSUMPTION HAVE BEEN ACHIEVED IN THE LATEST GENERATION OF TURBOSHAFT ENGINES, AND THE DOWNWARD TREND IN SFC IS EXPECTED TO CONTINUE. REGENERATIVE ENGINES OFFER THE POTENTIAL FOR SUBSTANTIAL FURTHER REDUCTIONS IN FUEL CONSUMPTION. PAST STUDIES CONCLUDED THAT THE INCREASED WEIGHT OF THE REGENERATIVE ENGINE IS GREATER THAN THE FUEL WEIGHT SAVING. WITH THE EMPHASIS ON FUEL EFFICIENCY, THE REGENERATIVE ENGINE MAY BECOME A MORE ATTRACTIVE OPTION.

THE EXPECTED 7% REDUCTION IN TURBOSHAFT ENGINE SFC OVER THE NEXT 15 YEARS WOULD PRODUCE A DIRECT 7% IMPROVEMENT IN HELICOPTER FUEL EFFICIENCY. ALTHOUGH THE EFFECTS ARE NOT PRESENTED. FURTHER FUEL SAVINGS OF 15 TO 25 PERCENT FOR THE REGENERATIVE ENGINE APPEARS TO BE AN ATTRACTIVE OPPORTUNITY.

AIRFRAME DRAG - CHART #5

AIRFRAME DRAG LEVELS FOR FIXED WING AND ROTARY WING TRANSPORTS ARE MARKEDLY DIFFERENT. ALTHOUGH THE HELICOPTER TREND IS TOWARD CLEANER DESIGNS, FIXED WING AIRCRAFT ARE TEN TIMES CLEANER THAN HELICOPTERS. THE TECHNOLOGY FOR HELICOPTER FUSELAGE DRAG REDUCTION IS AVAILABLE AND BASICALLY NO DIFFERENT FROM AIRFRAME TECHNOLOGY - ELIMINATE AREAS OF SEPARATION, THINNER PYLONS, INTERNAL FUEL, RETRACTABLE LANDING GEAR, REDUCED LEAKAGE, NO MAJOR PROTRUSIONS AND REDUCED MOMENTUM LOSSES. THE ONE UNIQUE HELICOPTER PROBLEM THAT DOES NEED A STRONG EFFORT IS THE REDUCTION OF ROTOR HUB DRAG. THE USE OF COMPOSITES FOR HUBS WILL HELP REDUCE FRONTAL AREA AND THUS REDUCE HUB DRAG. TO REALIZE A SUBSTANTIAL REDUCTION IN HUB DRAG, MORE ANALYTICAL AND EXPERIMENTAL EFFORT IS NEEDED. NONE-THELESS, HELICOPTER DRAG CAN VERY EASILY BE SIGNIFICANTLY IMPROVED USING TODAY'S TECHNOLOGY.

HELICOPTERS WITH ONE-HALF OF TODAY'S DRAG WOULD GAIN AN ADDITIONAL 7 TO 8% IN FUEL EFFICIENCY.

ROTOR PERFORMANCE - CHART #6

ROTOR PERFORMANCE IMPROVEMENTS DERIVE FROM TWO TECHNOLOGIES: COMPOSITE MATERIALS AND TRANSONIC AIRFOILS DESIGNED SPECIFICALLY FOR THE HELICOPTER ROTOR AERODYNAMIC ENVIRONMENT. USE OF COMPOSITE MATERIALS PROVIDES THE DESIGNER THE FREEDOM TO TAILOR THE ROTOR BLADE TO SATISFY AERODYNAMIC AND DYNAMIC REQUIREMENTS. INDUSTRY HAS MADE SIGNIFICANT PROGRESS IN THE DEVELOPMENT OF AIRFOILS FOR HELICOPTER ROTORS. AIRFOILS DEVELOPED IN THE EARLY 1970'S AND RECENTLY INTRODUCED IN SERVICE ARE PERFORMING AT IMPROVED EFFICIENCY LEVELS. THE NEXT GENERATION OF AIRFOILS NOW BEING TESTED IN WIND TUNNEL ROTOR TESTS HAVE DEMONSTRATED THE POTENTIAL FOR IMPROVED EFFICIENCY AS WELL AS SPEED IN EXCESS OF 200 KNOTS. THESE NEW AIRFOILS ARE READY FOR FULL SCALE DEVELOPMENT THAT WILL PROVIDE A SUBSTANTIAL INCREASE IN L/D WITH THE MAXIMUM EFFICIENCY OCCURRING AT A SPEED OF 180 KNOTS.

RESEARCH AIMED AT DEVELOPING AIRFOILS FOR THE 1990'S HAS BEGUN. ALTHOUGH EACH STEP IS INCREASINGLY DIFFICULT, ADVANCES IN TRANSONIC AERODYNAMICS AND ADVANCES IN DEFINITION OF THE ROTOR AERODYNAMIC ENVIRONMENT WILL PROVIDE THE ELEMENTS NEEDED TO ACHIEVE FURTHER SUBSTANTIAL IMPROVEMENTS.

ACHIEVING A ROTOR L/D OF APPROXIMATELY 12 WOULD PROVIDE AN 11 PERCENT INCREASE IN FUEL EFFICIENCY.

COMBINED EFFECT - CHART #7

THE ARITHMETIC SUM OF ALL THE ELEMENTS ADD UP TO A 30 PERCENT GAIN IN FUEL EFFICIENCY. MORE THAN HALF OF THIS GAIN DERIVES FROM AIRFRAME DRAG REDUCTION AND MORE EFFICIENT ROTORS.

THE SYNERGISTIC EFFECT OF COMBINING THESE ELEMENTS OF ADVANCED TECHNOLOGY IN A NEW DESIGN FAR EXCEEDS THE SUM OF THEIR INDIVIDUAL CONTRIBUTIONS. THE COMBINED EFFECT OF A NEW DESIGN INCORPORATING THESE ADVANCED TECHNOLOGIES RESULTS IN A FUEL EFFICIENCY GAIN OF MORE THAN 50%. IN ADDITION, THE BEST RANGE CRUISE SPEED CAN BE EXPECTED TO INCREASE TO 200 KNOTS WHICH, WHEN COMBINED WITH THE FUEL SAVINGS, WILL HAVE A MAJOR IMPACT ON OPERATING COSTS.

REDUCED DIRECT OPERATING COSTS - CHART #8

THE RESULTS OF A FUEL EFFICIENT HELICOPTER DESIGN TRANSLATES INTO REDUCED DIRECT OPERATING COST. SAVINGS OF 25 TO 40% CAN BE ACHIEVED FROM THE COMBINED EFFECTS OF ADVANCED ROTORS, DRAG REDUCTION, ADVANCED ENGINES AND USE OF ADVANCED STRUCTURAL MATERIALS AND DESIGN.

RESEARCH NEEDS - CHART #9

TO ACHIEVE THE HIGHER SPEED POTENTIAL OF HELICOPTERS WILL REQUIRE ADVANCES IN AERODYNAMICS THAT ADDRESS MORE THAN POWER REQUIRED. AERODYNAMICS RESEARCH MUST ALSO ADDRESS NOISE, BLADE AND CONTROL LOADS, VIBRATION, TRIM AND CONTROL, AND STABILITY. ALL THESE IN ONE WAY

OF ANOTHER IMPACT OPERATOR ECONOMICS. THE INDUSTRY NEEDS A STRONG NASA RESEARCH PROGRAM THAT DEVELOPS VALIDATED ANALYTICAL METHODS AND VALIDATED SMALL SCALE WIND TUNNEL TEST TECHNIQUES THROUGH A COORDINATED PROGRAM OF LARGE SCALE WIND TUNNEL VALIDATION TESTS AND FLIGHT VALIDATION TESTS. THIS WILL PROVIDE INDUSTRY WITH THE NEEDED VALIDATED ANALYTICAL METHODS AND VALIDATED SMALL SCALE WIND TUNNEL TEST TECHNIQUES SO THAT WE CAN PROCEED DIRECTLY TO LOW RISK CONCURRENT DESIGN, DEVELOPMENT AND CERTIFICATION OF NEW PRODUCTS. THIS WILL PRODUCE NOT ONLY FUEL EFFICIENT DESIGNS, BUT ALSO LOWER INITIAL COST PRODUCTS, LOWER OPERATING COSTS, AND SHORTER DEVELOPMENT SCHEDULES.

Fuel Cost Impact

Helicopter Direct Operating Cost Growth Commercial Operators

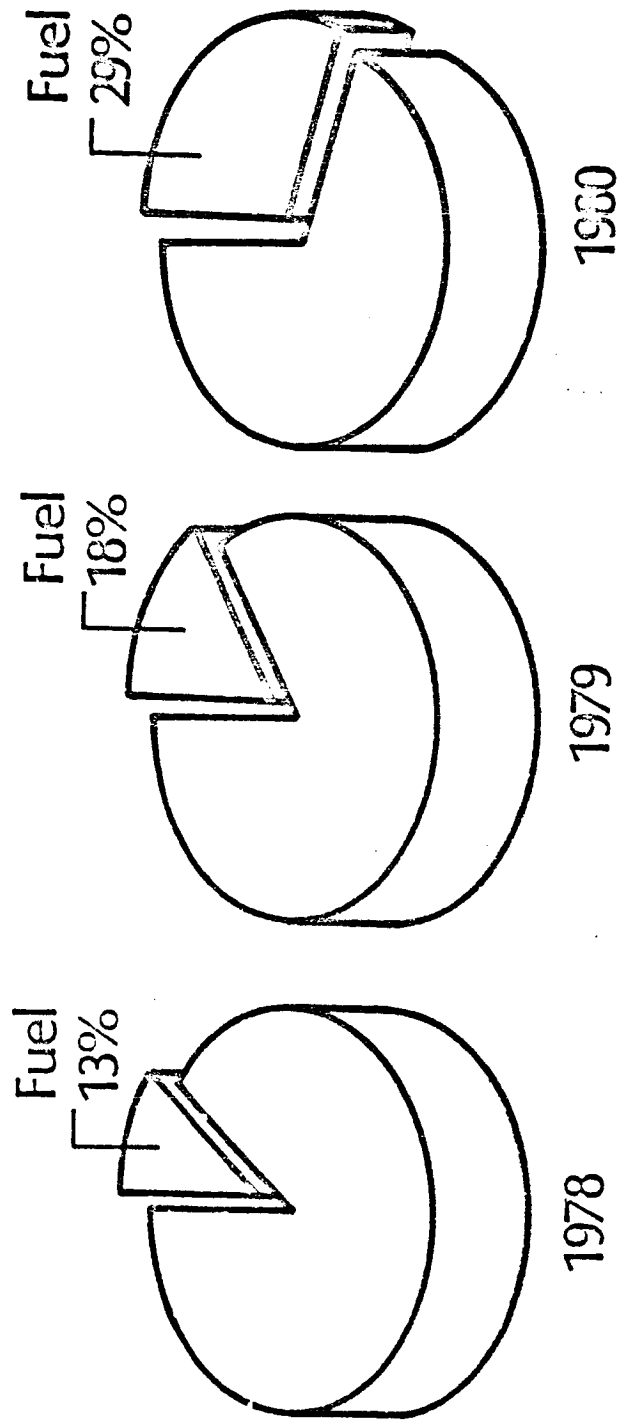


Chart 1.

Fuel Efficiency

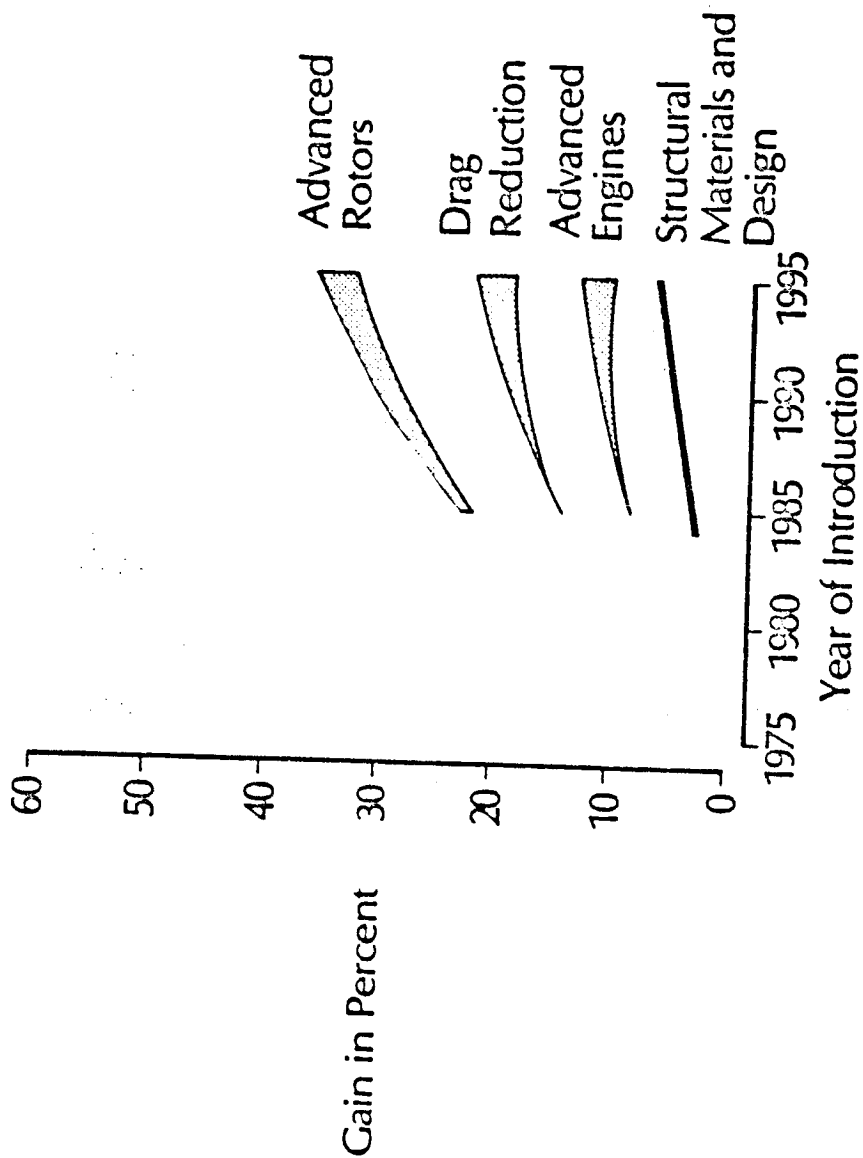


Chart 2.

Weight Empty Trend

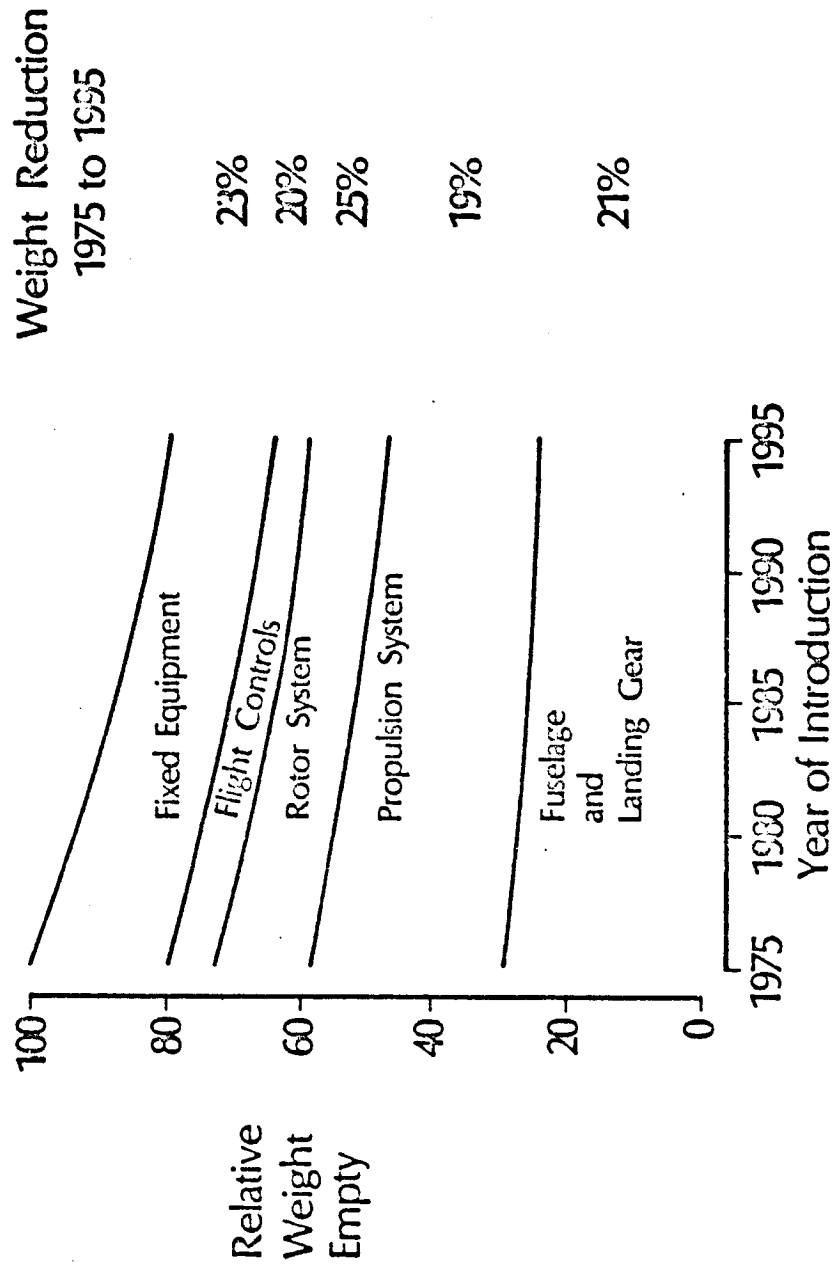


Chart 3.

Engine Fuel Consumption Trend

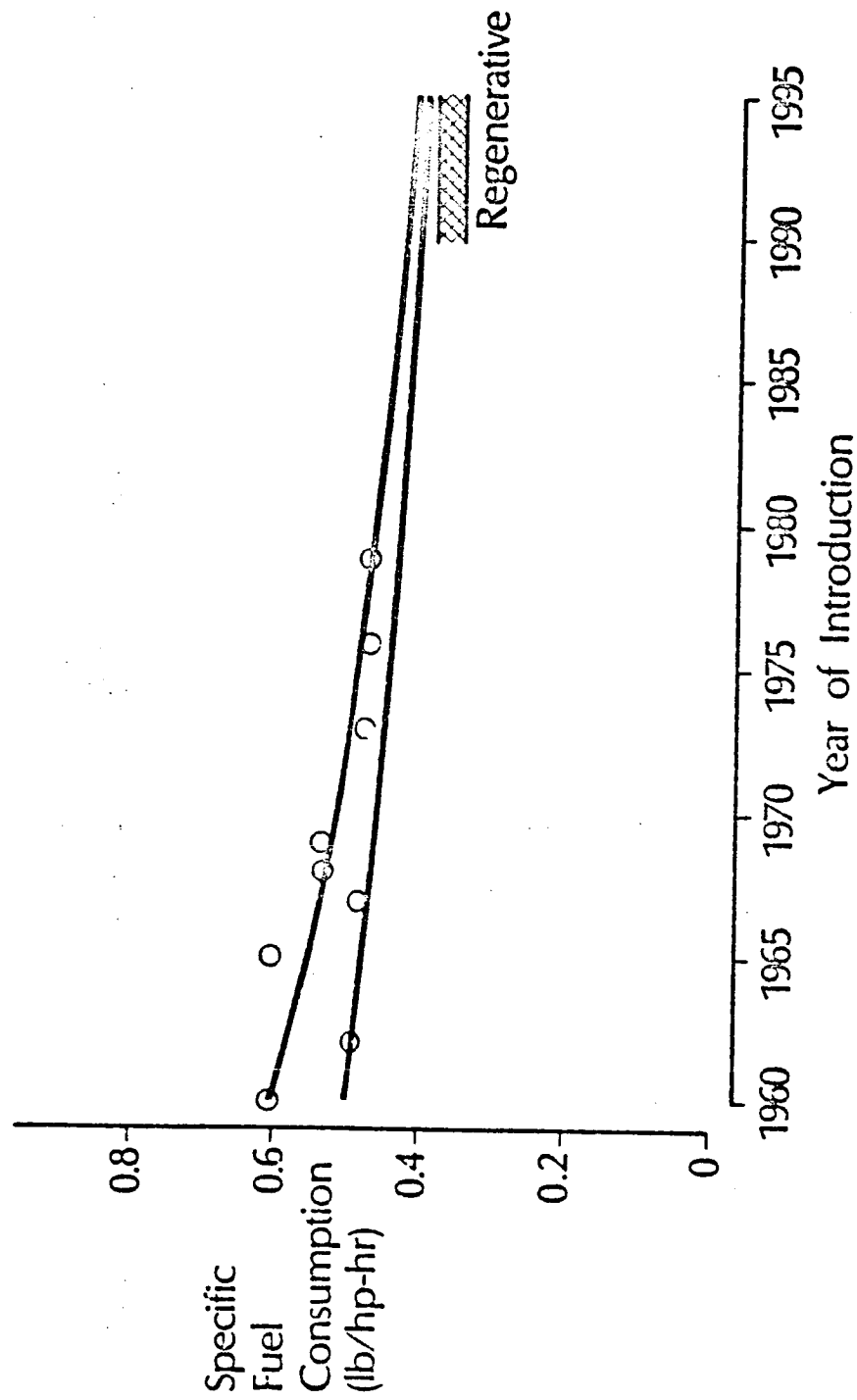


Chart 4.

Airframe Drag Trend

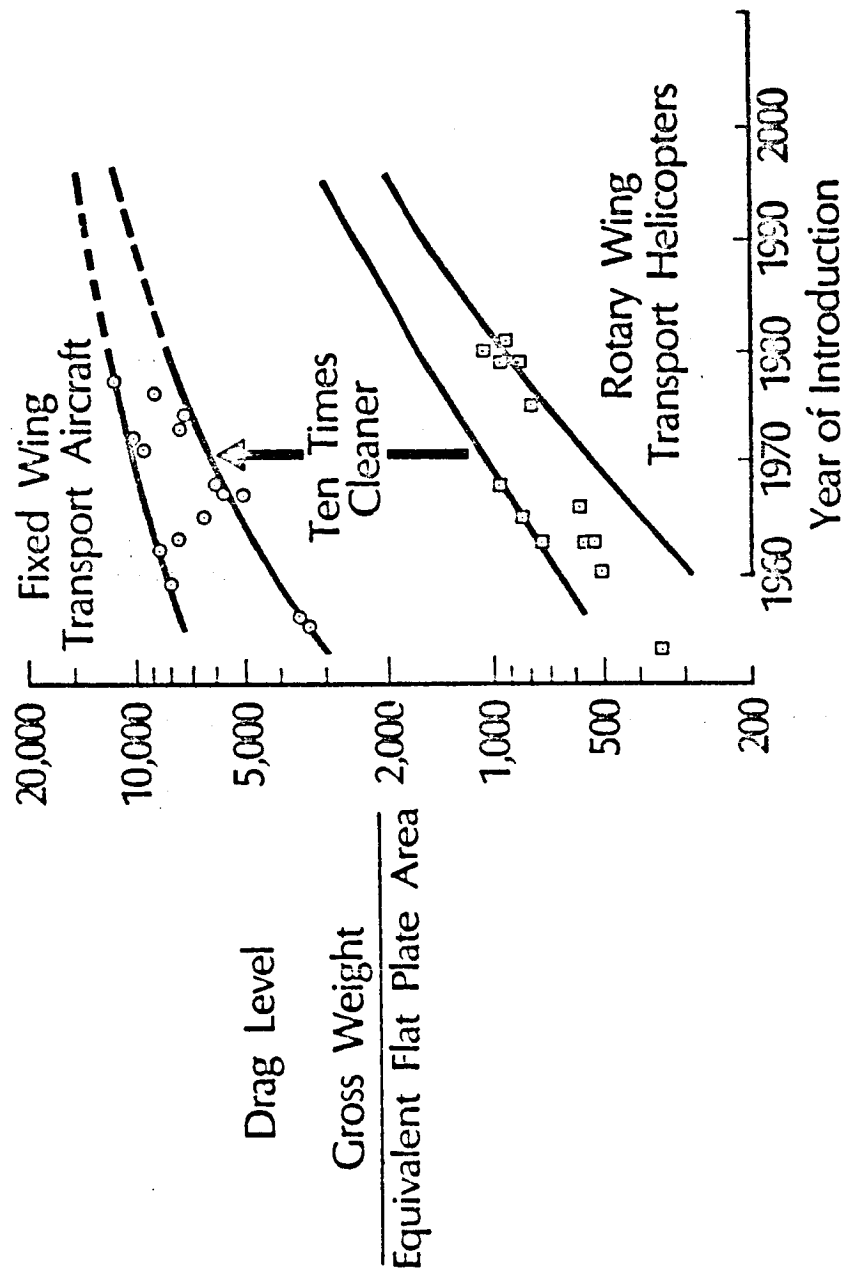


Chart 5.

Rotor Performance

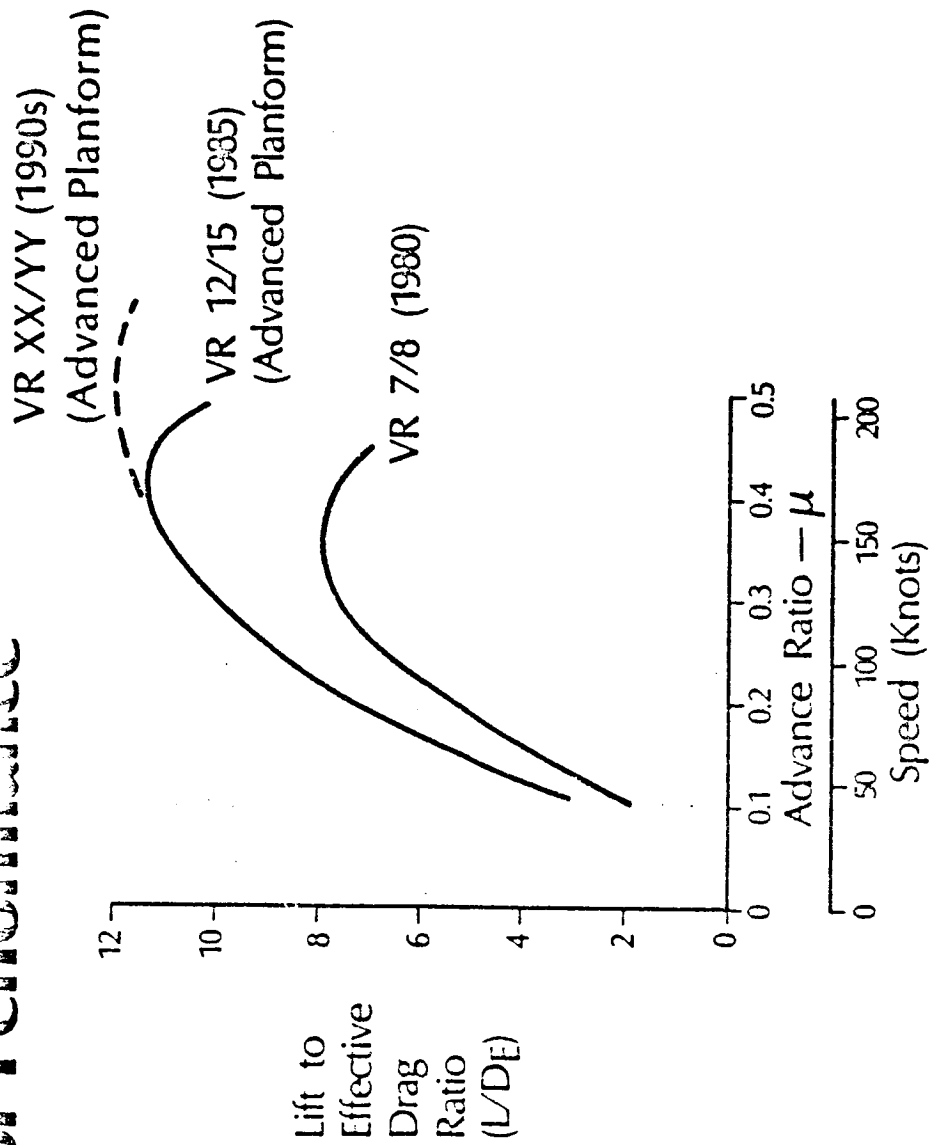


Chart 6.

Fuel Efficiency

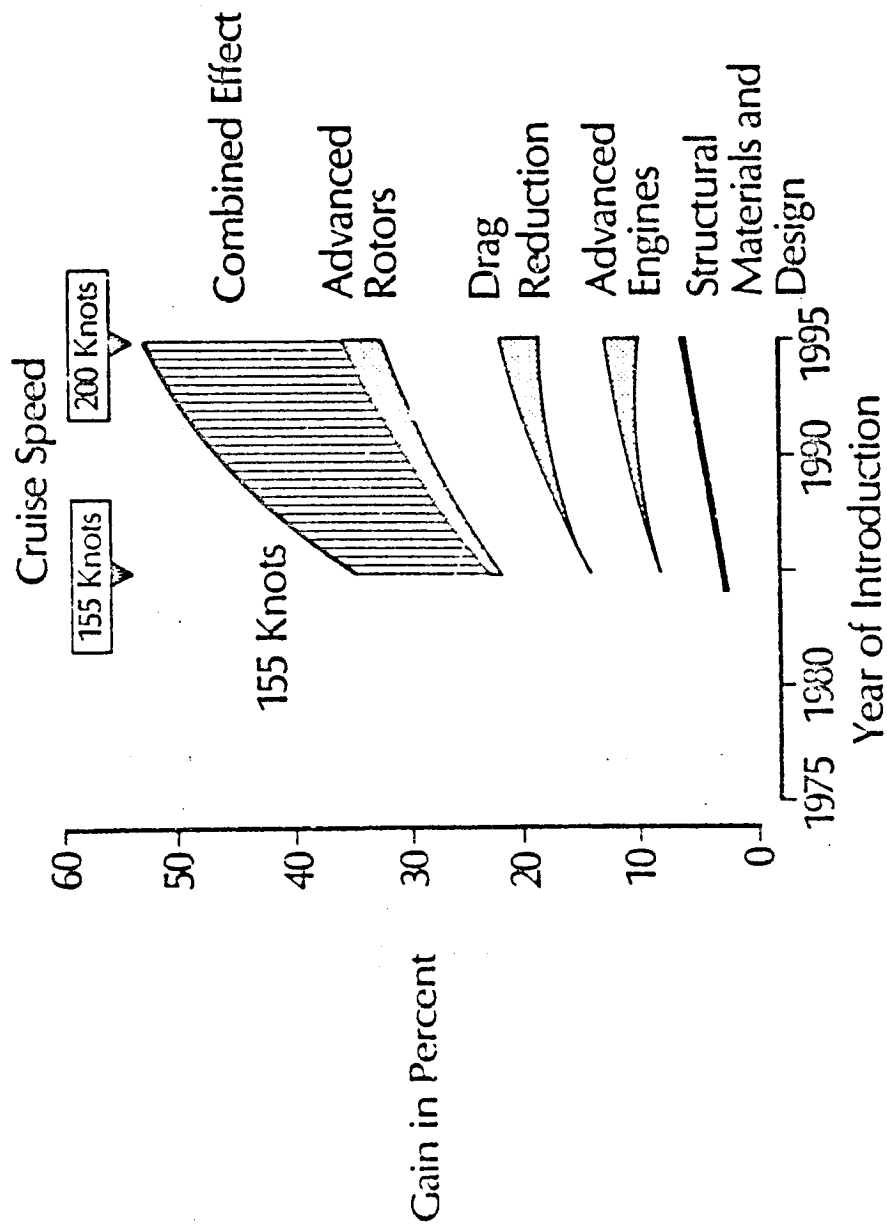


Chart 7.

Reduced Direct Operating Cost

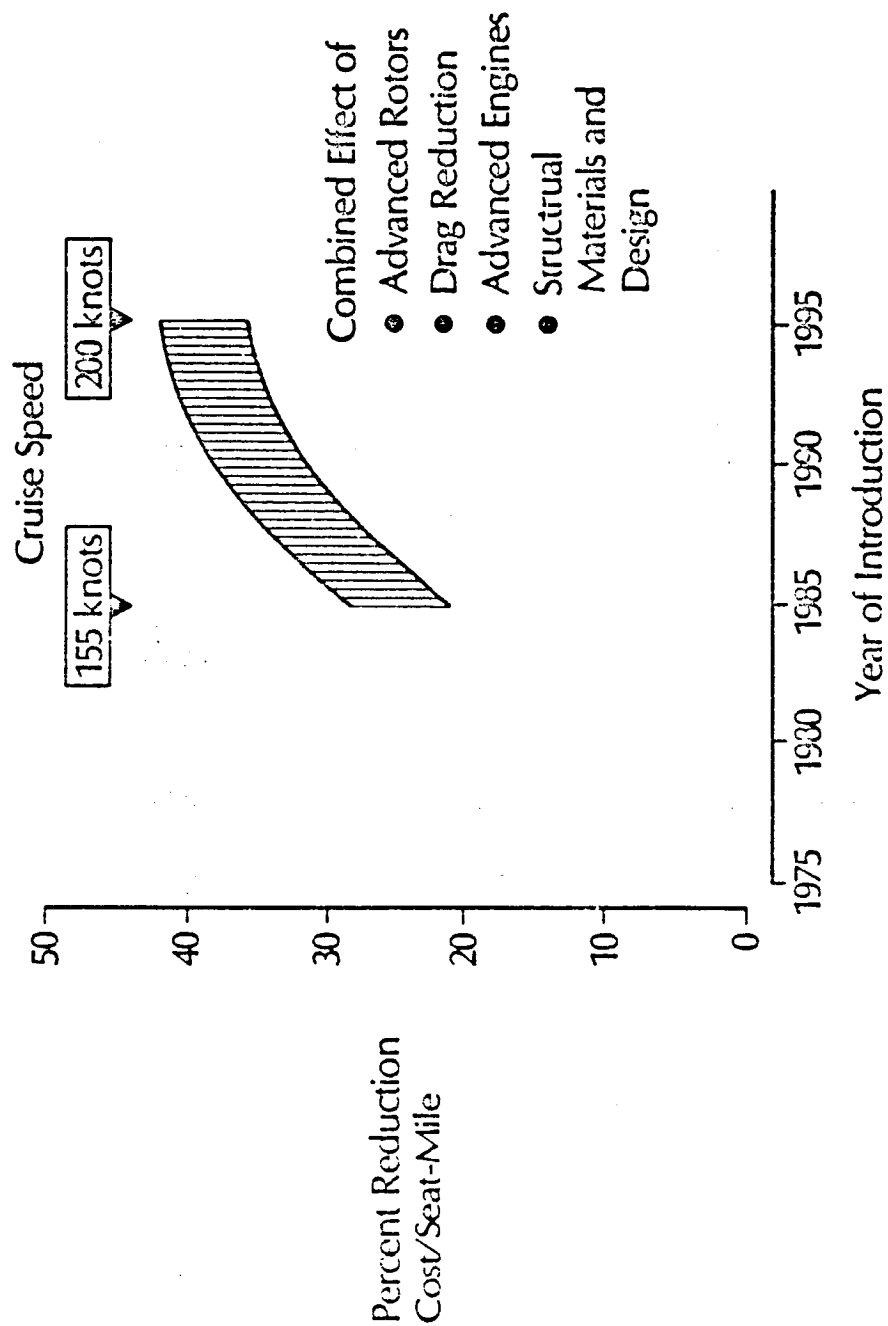


Chart 8.

Aerodynamic Interactions of the Single-Rotor Helicopter Configuration

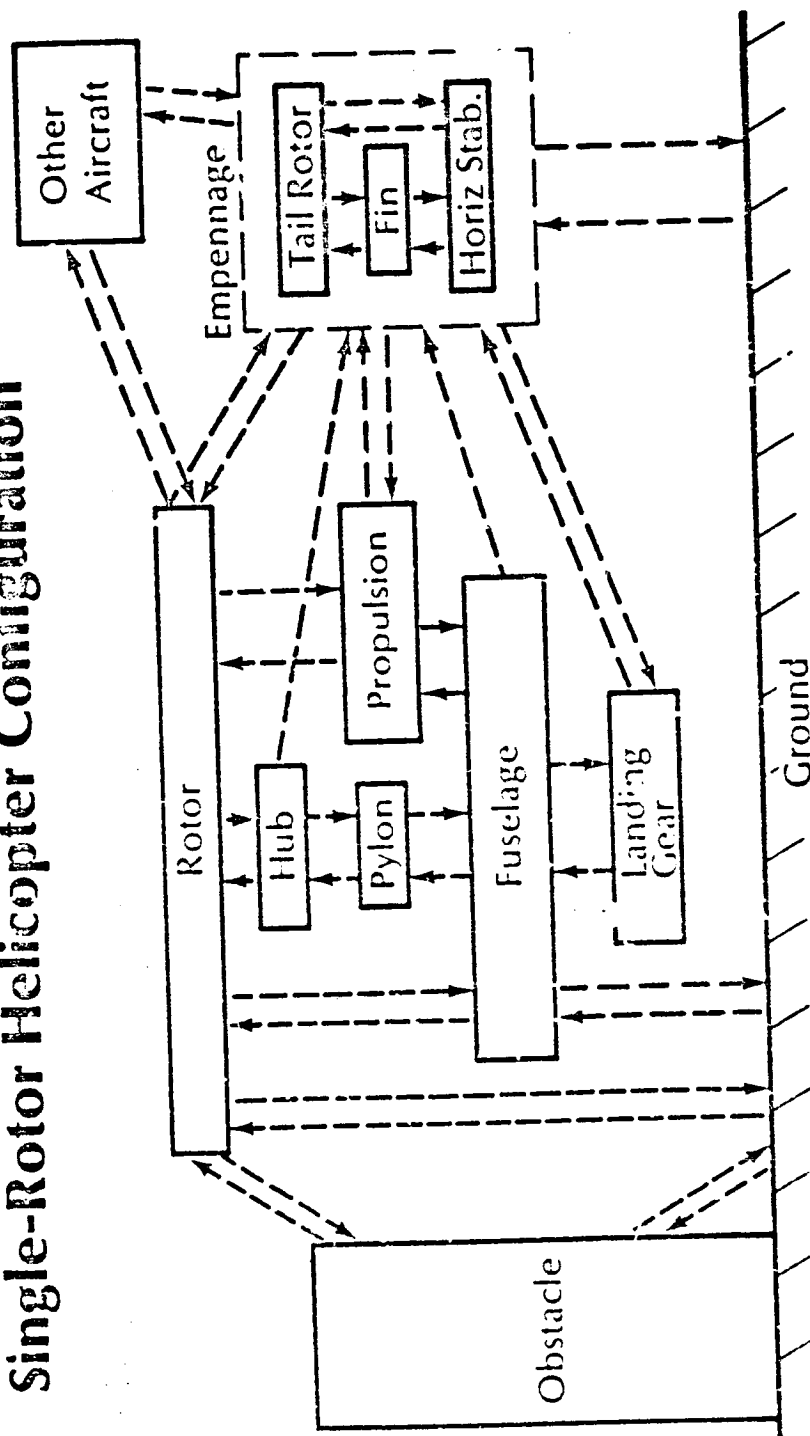


Chart 9.

To Be Responsive to Operator Needs Rotor Aerodynamics and Rotor/Rotor/Airframe Interactions Needs

NASA's Research to Develop

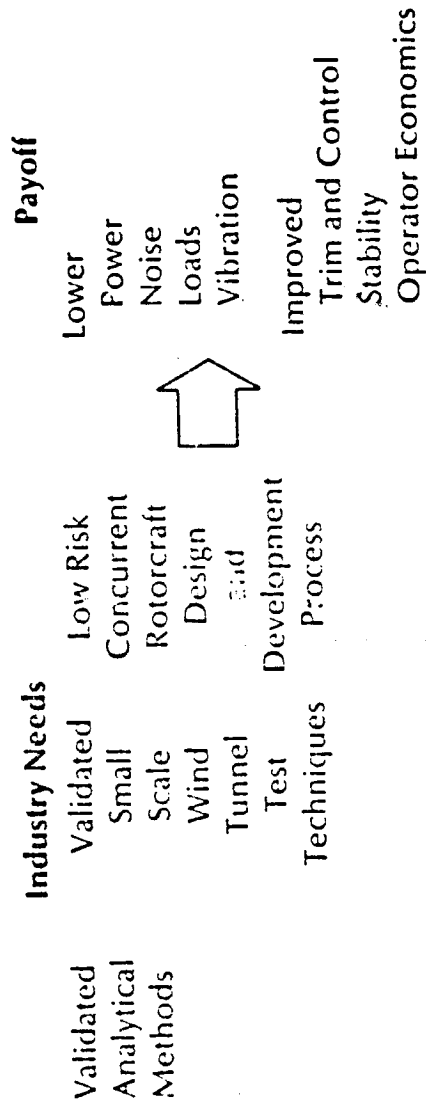
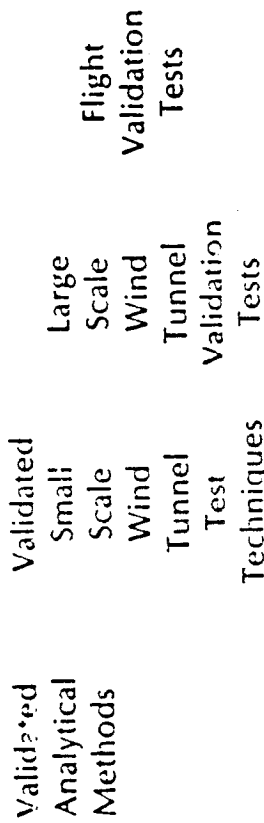


Chart 10..

HAA/NASA ADVANCED ROTORCRAFT TECHNOLOGY WORKSHOP

COMMENTS ON PERFORMANCE TECHNOLOGY

Troy M. Gaffey

I have only one point to make with respect to NASA's program for rotorcraft aerodynamics--"The accuracy of rotorcraft performance prediction is inadequate because of inadequate mathematical models." Generally speaking, power required can be predicted to 3% accuracy using state-of-the-art methodology. Three percent may sound good, but keep in mind that for a 10,000 pound helicopter, it represents two passengers in terms of hover payload and a 21% error in terms of OEI altitude (Fig. 1).

Industry must aim for 1% or better prediction in hover and minimum power required. To achieve this goal much improved, practical analytical models of rotorcraft aerodynamics are required (Fig. 2). In order to validate these improved analytical models, test techniques must be improved to provide a data base accurate to better than 1%.

NASA's research in these areas can make a significant contribution to improving the accuracy of performance prediction.

FIGURE 1.

PREDICTION OF MINIMUM POWER REQUIRED
TO WITHIN 3% IS NOT GOOD ENOUGH

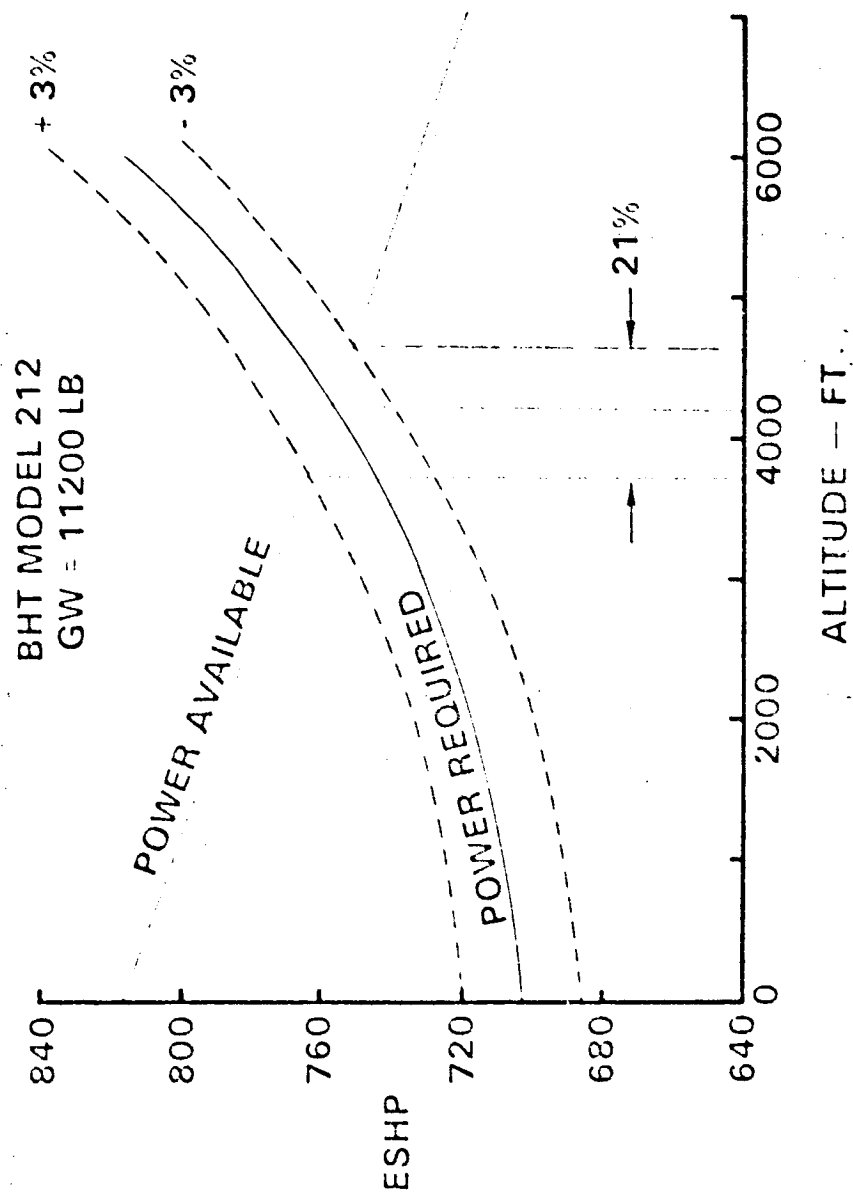


FIGURE 2.

RECOMMENDED PROGRAMS TO REDUCE PERFORMANCE PREDICTION UNCERTAINTY

- IMPROVED PRACTICAL ANALYTICAL MODELS
 - COMPRESSIBILITY
 - NON-UNIFORM INFLOW
 - ROTOR/AIRFRAME/PROPULSION INTERACTIONS
- IMPROVED TEST TECHNIQUES TO PROVIDE A MORE ACCURATE DATA BASE

Summary of Remarks of Jack Landgrebe
(Chief, Aeromechanics Research Section, United Technologies Research Center)
Panelist, Aerodynamics and Structures Technical Session
HAA/NASA Advanced Rotorcraft Technology Workshop

In addition to identifying NASA technical goals and selecting and prioritizing the rotorcraft technology tasks required to accomplish the goals, sufficient attention should be given to other aspects related to the means of achieving those goals in a manner which NASA and industry operate in a coordinated and efficient manner. I shall label the four aspects which I will address as "the four Is":

- Inter-relationship
- Interdiscipline
- Integration
- Interaction

Inter-relationship

Greater attention should be given to the "inter-relationship" of the various technical areas in the selection of specific programs and tasks related to rotorcraft aerodynamics technology. It is well recognized that aerodynamic studies, particularly those related to helicopter airflow and rotor airloads, can be directed to the objectives of performance, structural loads, vibrations, handling qualities, stability, and/or noise. The requirements for each of these objectives and how they are inter-related to the aerodynamic characteristics must be recognized in the formulation of research programs. For example, it is well known that in the establishment of a project related to blade airload methodology, that compromises must be made regarding the level of analytical sophistication and computer resource requirements. For any new analysis the selection of technical assumptions and the compromise between accuracy and computer time and storage utilization directly determines which of the above technical objectives the resulting airloads prediction is applicable to. This is exemplified by the much more stringent aerodynamic methodology requirements for vibrations and noise prediction as compared to performance. In selecting and prioritizing the specific programs and tasks for NASA's rotorcraft aerodynamics plan it is recommended that greater attention be given to avoiding the tendency to subdivide and separate technical objectives and project selection into the categories of performance, vibrations, etc., and instead direct aerodynamic methods and tests toward consideration of reasonable combinations of these objectives.

Interdiscipline

In order to address the inter-relationship between the above technical objectives, the rotorcraft technologists and planners must become increasingly interdisciplinary in their outlook and capabilities. The requirements for combining technical disciplines (aerodynamics, dynamics, structures, acoustics, etc.) in research programs is increasing as the state of rotorcraft technology matures and problems directed at the total aircraft system become more prevalent. Aeroelastics, aeroacoustics, etc. must become the interdisciplinary framework for technical projects. Technical plans, personnel capabilities, and organizational structure should increasingly reflect this requirement.

Integration

More advanced planning should be given to how the results of analytical studies and experimental programs will be integrated into the rotorcraft design and diagnostic computer codes. Although it is well recognized that fundamental studies of mechanisms and behavior are very much needed in the rotorcraft aerodynamics and structures fields, attention during project formulation as to how the data will eventually be integrated into the engineering procedures utilized by the helicopter industry will facilitate the transition from research results to engineering practice.

Interaction

Government/industry planning and technical interaction in the rotorcraft field has increased in recent years as exemplified by this Advanced Technology Workshop. However, considering the recent increase in NASA rotorcraft activity and the accompanying re-organization and influx of new staff, the following is recommended. NASA/industry interaction should increase to the level such that there is a much improved co-awareness of current and planned activities among technical counterparts to avoid redundant efforts, improve cooperation on related efforts, and make greater use of existing computer codes and experimental facilities.

Performance Session - Discussion

- . More efficient use of facilities is needed, and better communication between NASA and industry.
- . Extreme accuracy (1%) is needed in performance prediction and performance measurement.
- . Aerodynamics involves interdisciplinary interrelationships with other fields such as vibration and acoustics. Inter-action with workers in those fields is needed to integrate research and development.
- . Performance prediction at low speed under the transient conditions involved after engine failure needs attention. Operators want real twin engine safety and this implies adequate OEI performance. The regime is difficult to analyze or to test. Perhaps RSRA could be used.
- . Aerodynamic load prediction is not yet adequate for acoustics prediction.
- . Airloads on tail surfaces have become important to vibration.
- . Helicopter companies use far less large scale wind tunnel testing than fixed wing companies. The complexity of the problem suggests this is not right.

Acoustics Panel

Chairman and Keynote	- Robert King, Hughes
NASA Representative	- J. Phillip Raney, Langley
 William Wall's	 - Boeing Vertol
 Charles Cox	 - Bell
 David Jenney	 - Sikorsky
 Discussion	



Robert J. King
Hughes Helicopters Inc.

Summary:

The challenges facing the helicopter acoustics discipline have intensified recently. Upcoming federal regulations will require reduced external noise generation and reduced community noise exposure at heliports. The increasing use of the helicopter as a large scale people mover and VIP transport has placed higher priority on improvement of the internal noise environment. These requirements run counter to long term trends of higher speeds and lighter weight, more rigid structures which have tended to increase noise generation. Technology is required to reverse these trends.

The primary industry concern regarding the new noise regulations is that they impose noise reductions which will require economic penalties to attain with the current state of the art in noise control. Technology can be developed to permit redesign of current production helicopters and design of new models to meet such rules with reasonable economic impact, but it is not available now.

External Noise:

The first echelon problem area in external noise control is that of noise prediction. The currently available engineering type prediction methods do not produce results which provide reasonable confidence of meeting a rule without unacceptably large design margins. These margins are unacceptable because they necessitate large noise reductions which translate into economic penalties. Further, the engineering type prediction approach does not provide enough accuracy to properly rank and define noise sources for noise control tradeoffs and evaluation of noise reduction modifications. The research type prediction methods, which provide some promise of improvement, are severely limited in their application because of corresponding limits to aerodynamic load prediction. It is felt that a prediction approach combining the engineering and research methods is needed to treat the multi-source rotor noise problem with the desired accuracy, completeness, flexibility, and affordability. Development of such a method should be one of the major thrusts of the long term helicopter acoustics effort. The engineering methods must be improved through a greatly expanded experimental data base for use in the near term.

Turboshaft engine noise is an important secondary source of helicopter external noise that will emerge as a lower noise limit as rotor noise is controlled. It has received little attention in the past. Research must begin in earnest to develop means to control this noise, preferably at the source rather than via add-on silencing, so that they are available to complement lower rotor noise when needed.



Helipport noise regulations require a good deal more study before they can be established with a sound technical base. Available background information is aimed predominantly at fixed wing aircraft and there are strong reservations among those in the helicopter industry regarding their applicability to this type of vehicle. The accuracy of the basic noise descriptor is in question as is the critical footprint methodology by which heliport criteria will be applied. Noise abatement capabilities of the helicopter have not been investigated and incorporated into planning for such a rule and the basic environmental benefits which are its objective have not been properly assessed. The result, without the needed technology development, could be criteria which penalize the helicopter industry with doubtful gains for the community environment.

Internal Noise:

Internal noise prediction and control is in need of technology development like external noise. However; in addition, there is a lack of generally accepted criteria for internal noise in the commercial field. The discrete mid/high frequency dominated character of helicopter internal noise is quite different from that of transport category or general aviation airplanes. This character difference changes the relationships between noise level, speech interference, and annoyance such that criteria designed for more common noise environments can not be applied. These relationships must be quantified and applicable rating scales identified so that manufacturers and users can make meaningful criteria decisions.

The ability to predict internal noise levels and spectrum composition is similar to that described above for external noise. Application of soundproofing to interiors to attain noise goals is no longer adequate because of the trend to light weight more rigid structures coupled with more stringent criteria. Soundproofing will no longer do the job with acceptable weight fractions. With this simple add-on noise control measure unavailable to do the entire job, more sophisticated methods must be developed and used. These structural noise control methods must be applied, or at least allowed for, early in the helicopter design process. To do so requires that the extent of the noise problem and source/path features be identified early. Hence; prediction methods for internal noise are required for the same types of reasons that they are for external noise. Unfortunately these methods are less complete and reliable than those for external noise. They must be developed to the point where they can be used for reliable internal noise prediction in the preliminary design process so that the needed structural noise control measures can be incorporated into the system in a timely manner. This is absolutely necessary because it is an accepted fact that noise control accomplished as an add-on to an existing system is much more costly than that which is preplanned.



Recommendations:

Detailed research recommendations are made in the vugraph presentation. The key to both external and internal noise control is the definition of sources and development of valid detailed prediction methods for them. This provides the tools for controlling noise. More work is required on the development and verification of criteria for heliport noise descriptors and internal noise. Lastly, there must be an ongoing program of evaluation of noise reduction means as they are identified to determine their noise/cost payoffs relative to current methods.



HELICOPTER NOISE TECHNOLOGY INDUSTRY CONCERNS

- FEDERAL REGULATION OF HELICOPTER NOISE
 - DESIGN NOISE MARGINS REQUIRED — PREDICTION ACCURACY
 - COSTS OF ACHIEVING NOISE REDUCTION
 - PERFORMANCE
 - ECONOMIC
 - COMPETITIVE
 - PROVISION FOR INNOVATION
 - TWO SPEED ROTOR
 - TILT ROTOR
 - ASSESSMENT OF ENVIRONMENTAL BENEFITS

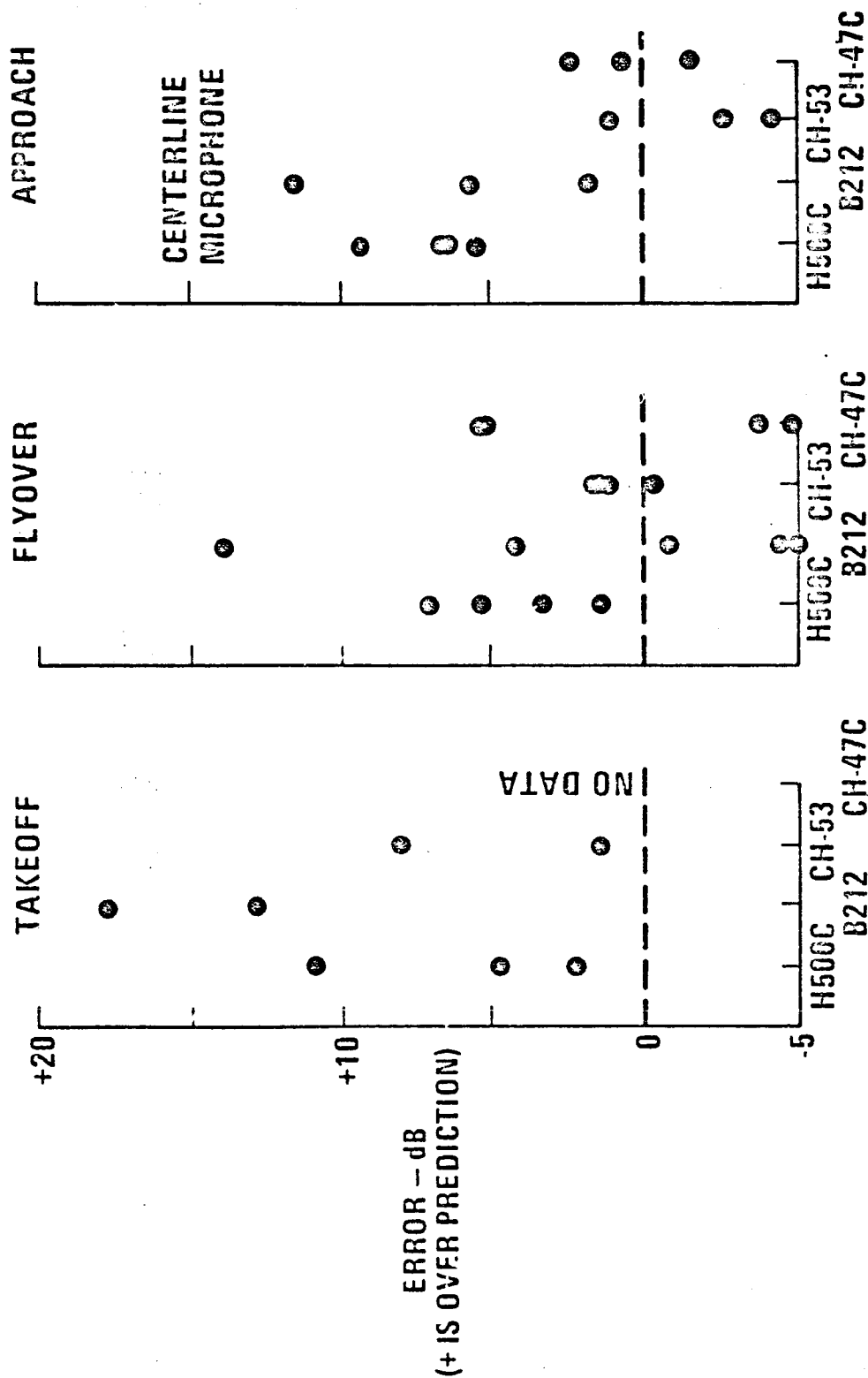
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HELICOPTER NOISE TECHNOLOGY PREDICTION ACCURACY (ENGINEERING APPROACH)

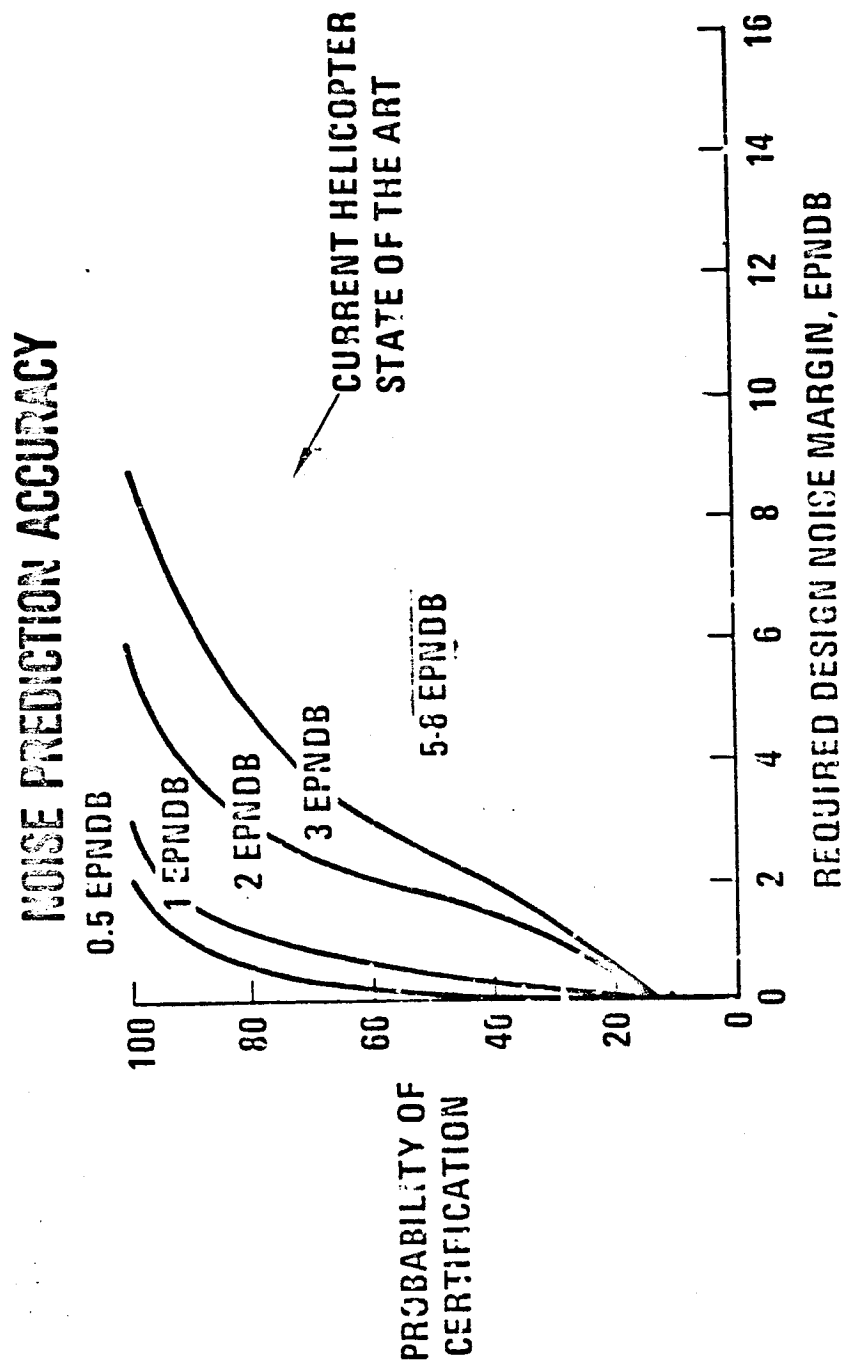


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HELICOPTER NOISE TECHNOLOGY PREDICTION ACCURACY



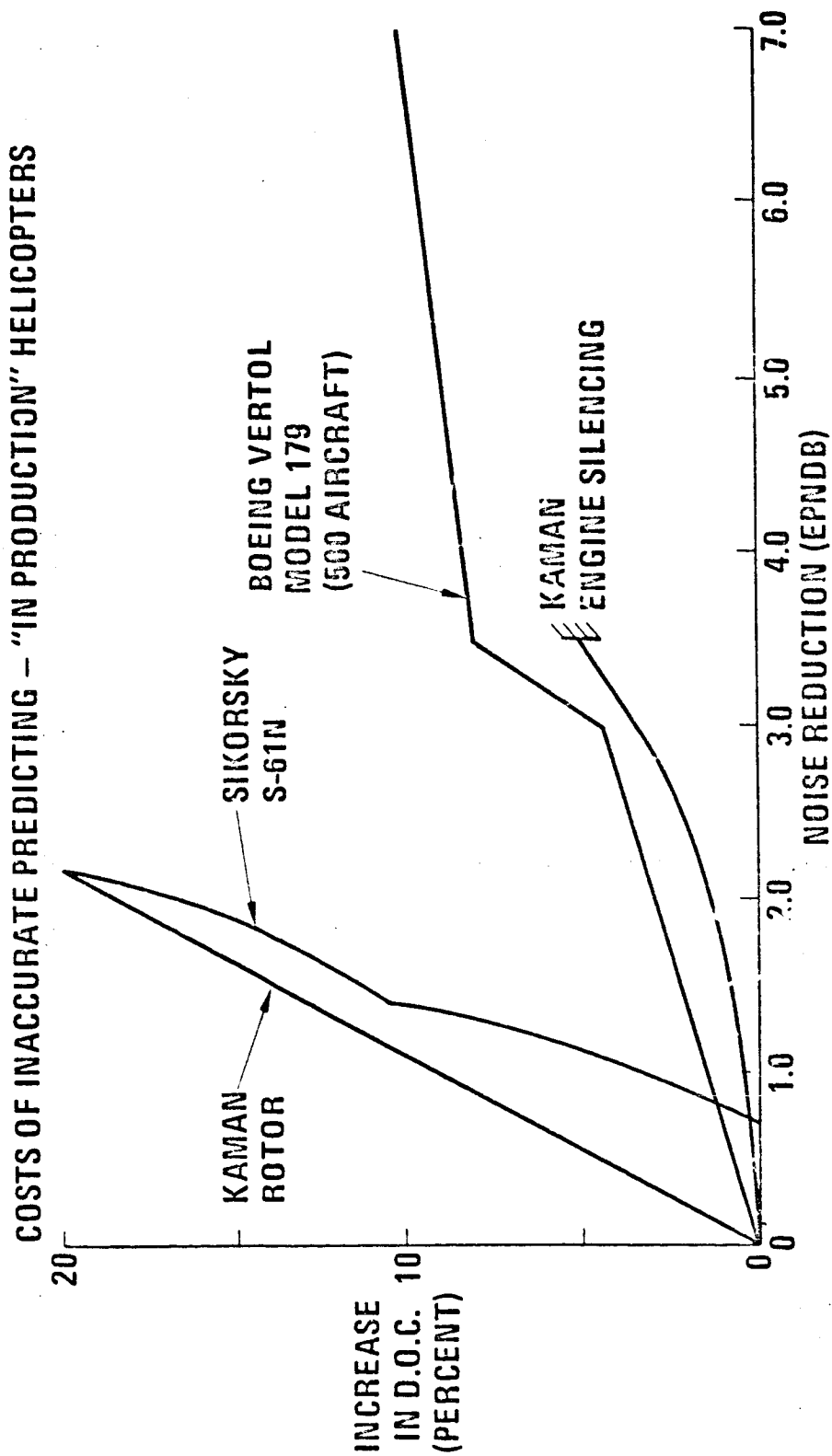
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HELICOPTER NOISE TECHNOLOGY COSTS OF NOISE REDUCTION



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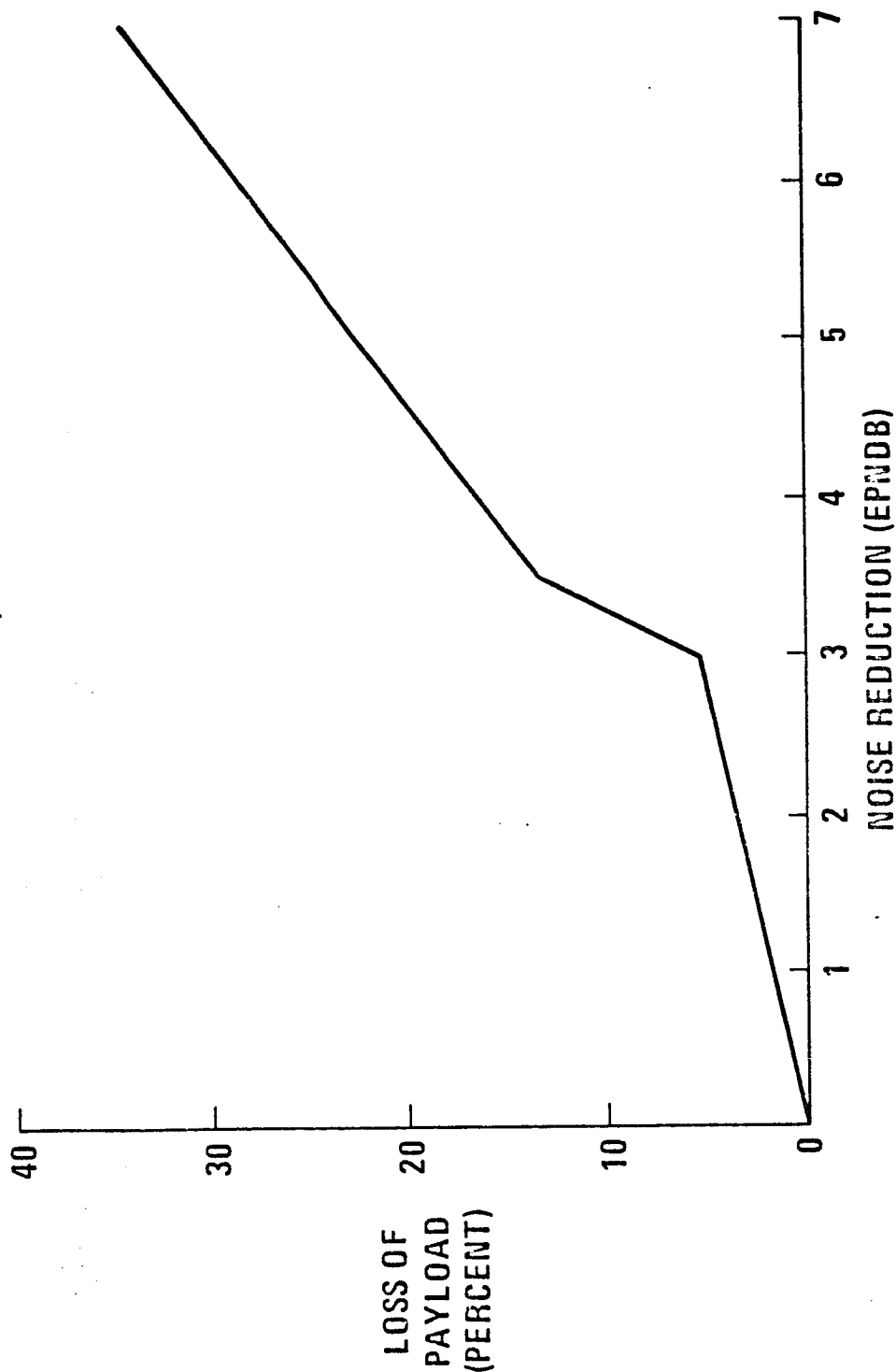
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PERFORMANCE COSTS OF TIP SPEED REDUCTION

BOEING VERTOL MODEL 179, CRUISE (FAA-EE-80-5)



LOSS OF
PAYLOAD
(PERCENT)

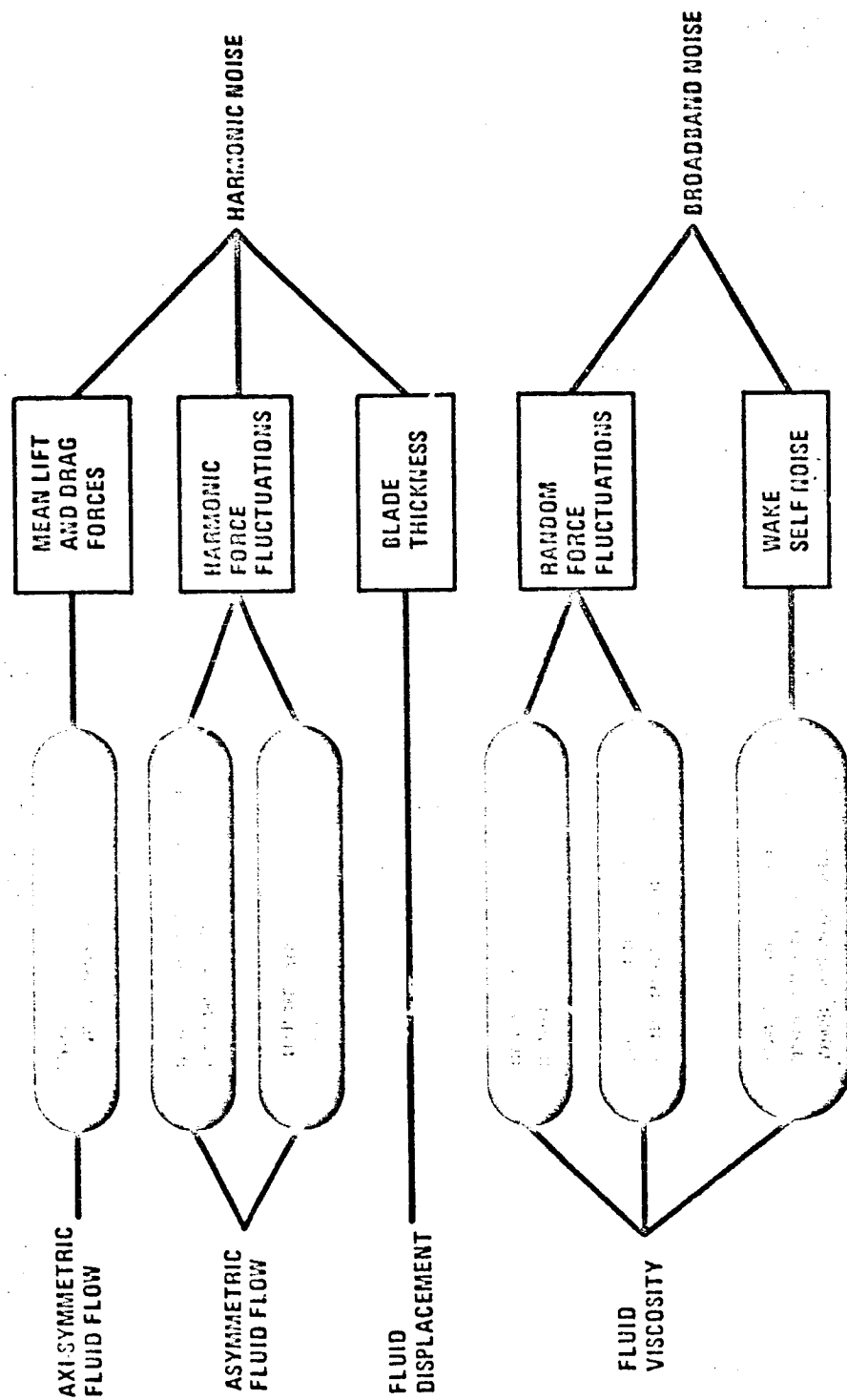
NOISE REDUCTION (EPNDB)

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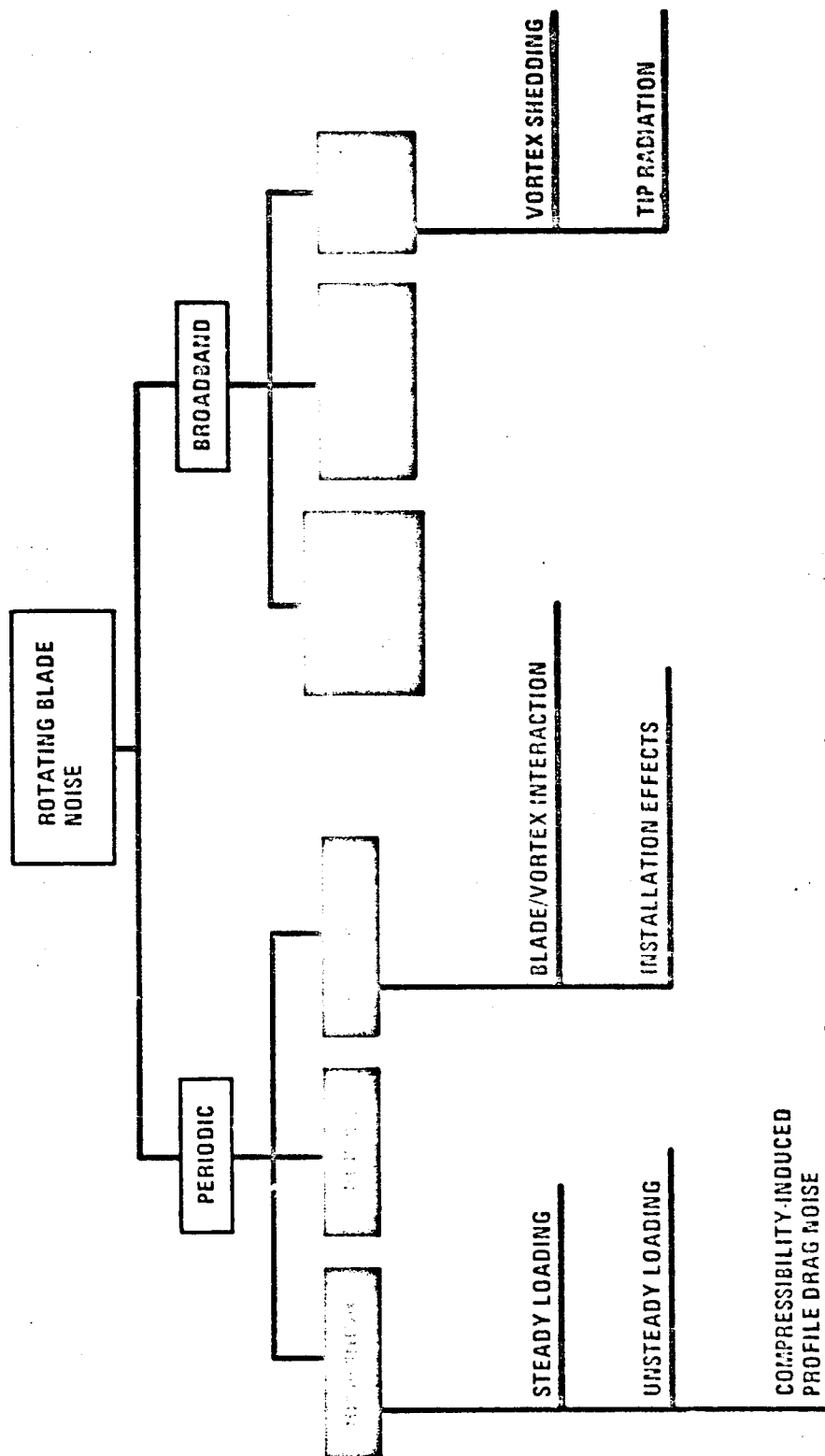


HELICOPTER NOISE TECHNOLOGY AERODYNAMIC SOURCES OF ROTOR NOISE — AHS



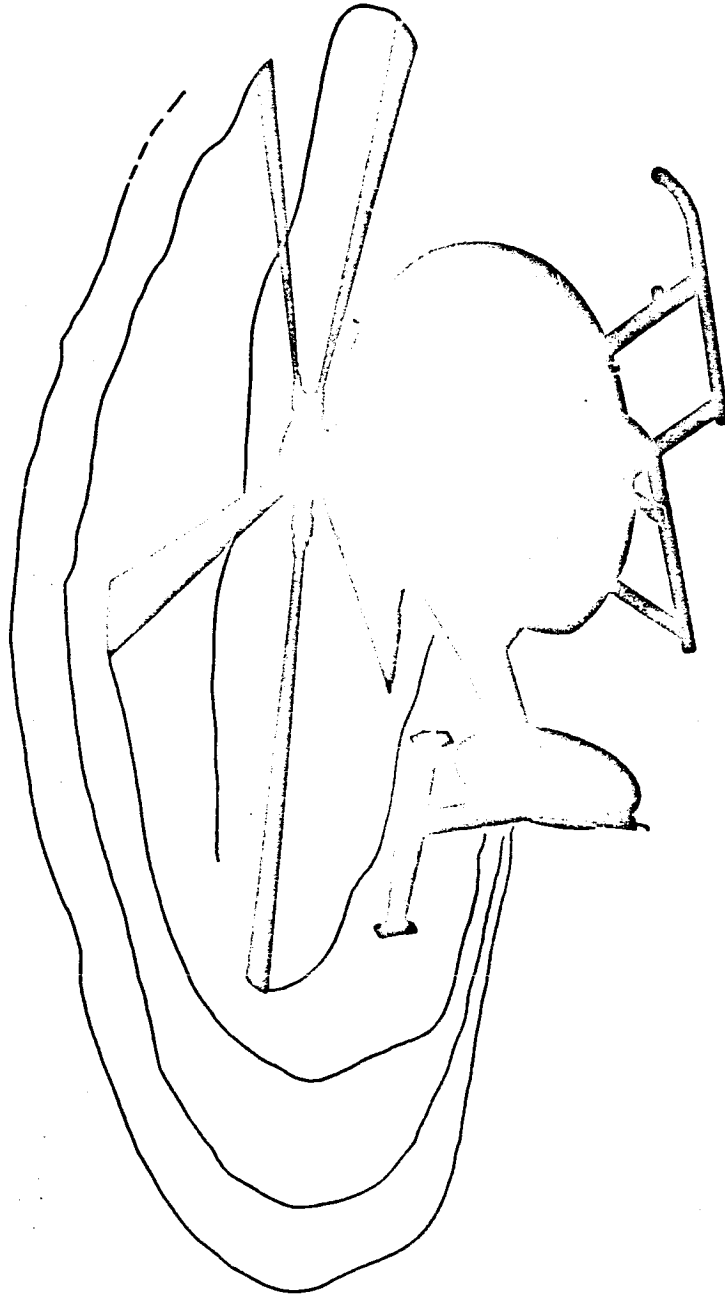


HELICOPTER NOISE TECHNOLOGY
**ROTATING BLADE NOISE
COMPONENTS — NASA LANGLEY**





WAKE INTERACTION



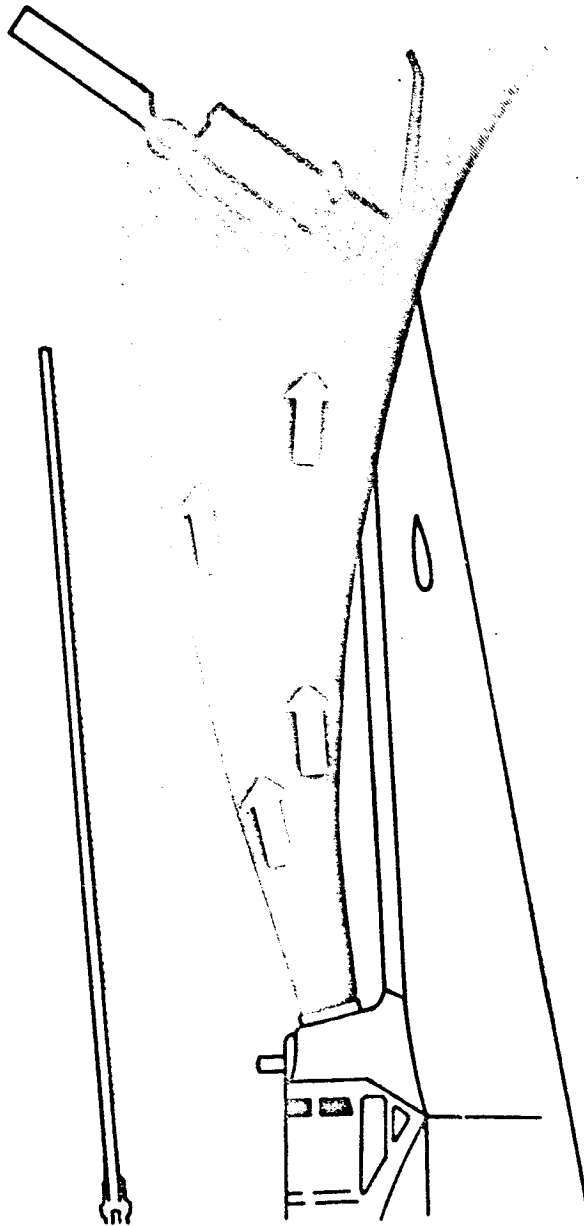
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HELICOPTER NOISE TECHNOLOGY INTERFERENCE



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PREDICTION ACCURACY

- ENGINEERING APPROACH

- EXAMPLE: HERON II WITH EMPIRICAL BROADBAND NOISE

- ADVANTAGES

- SIMPLE
- LOW COST
- FLEXIBLE

- DISADVANTAGES

- LIMITED ACCURACY (PARTICULARLY SPECTRUM)
- FREQUENCY BASED (NO PHASING)
- CAN EVALUATE ONLY GROSS GEOMETRY CHANGES (BLADE NUMBER, BLADE AREA)
- ASSUMES EQUAL BLADE SPACING

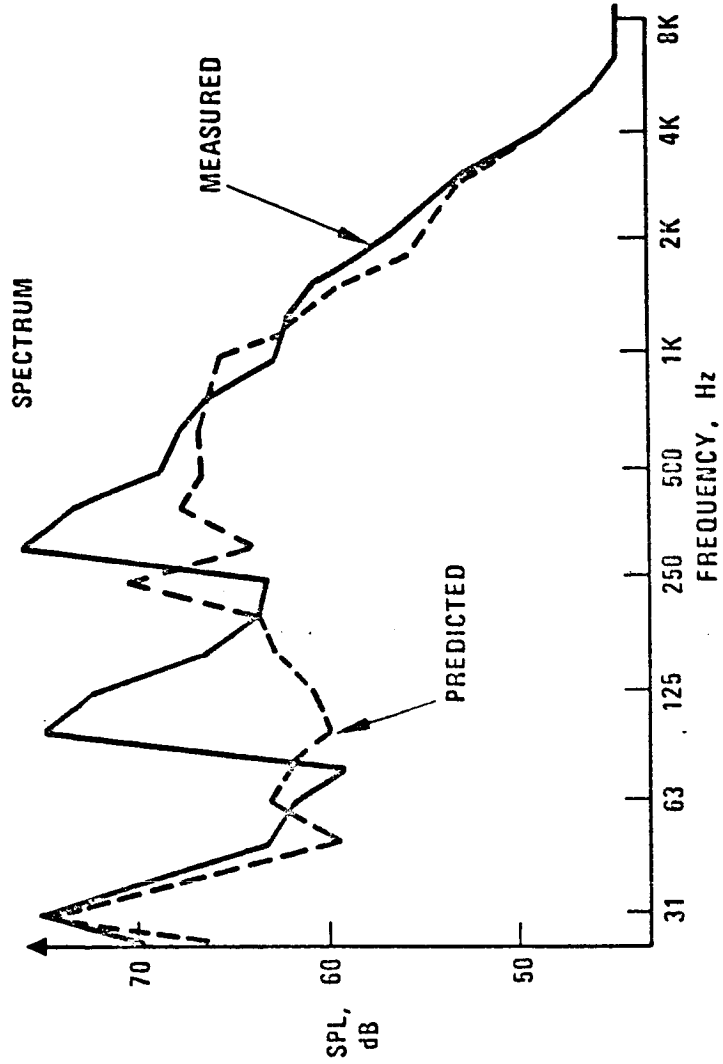
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HELICOPTER NOISE TECHNOLOGY
PREDICTION ERROR IS
DIRECTLY PROPORTIONAL
TO DETAIL ATTEMPTED

	3-POSITION EPNL	CENTERLINE EPNL	CENTERLINE PNLTMAX
MEASURED	88.3	88.7	89.4
PREDICTED	87.0	89.1	86.1
ERROR	1.3	1.6	3.3



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HELICOPTER NOISE TECHNOLOGY PREDICTION ACCURACY

• RESEARCH APPROACH

- EXAMPLE: FARRASSAT-NYSTROM PROCEDURE

• ADVANTAGES

- ACCURACY (IF INPUT AVAILABLE)
- TIME BASED (PHASING MAINTENANCE)
- CAN EVALUATE NOISE CONSEQUENCES OF GEOMETRY CHANGES

• DISADVANTAGES

- COSTLY TO RUN
- NO BROADBAND NOISE PREDICTION
- REQUIRES DETAILED AERODYNAMIC INPUT WHICH IS NOT PREDICTABLE

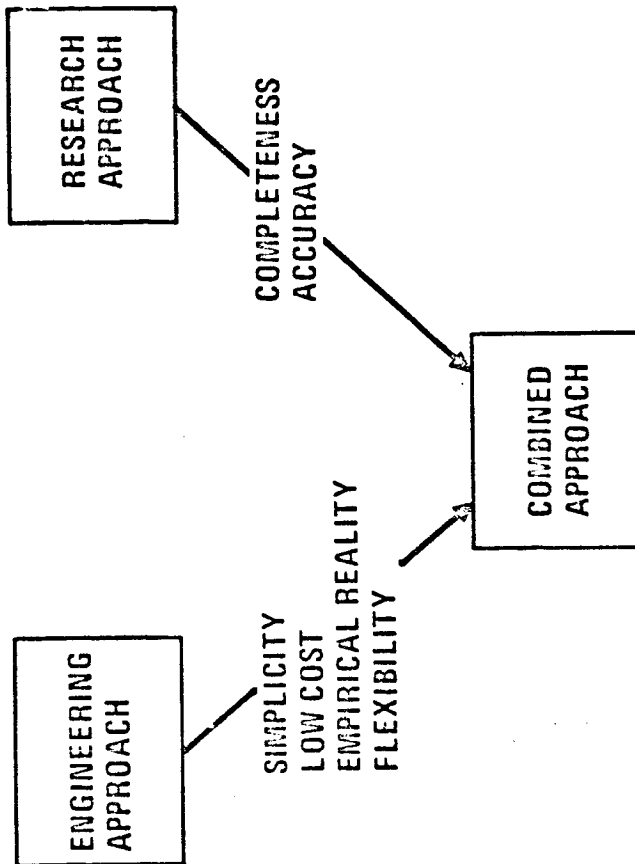
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HELICOPTER NOISE TECHNOLOGY PREDICTION ACCURACY

TYPES OF PREDICTION NOW PERFORMED



AVAILABLE

NEEDED



HELICOPTER NOISE TECHNOLOGY

TURBOSHAFT ENGINE NOISE

- ENGINE NOISE IS AN IMPORTANT SECONDARY SOURCE IN HELICOPTERS
- NOISE REDUCTION IS REQUIRED IN LOW/MID FREQUENCIES
 - SILENCING DIFFICULT — SIZE PROBLEM
 - SOURCE CONTROL PREFERRED
- ENGINE MANUFACTURERS IGNORE NOISE IN SHAFT ENGINES

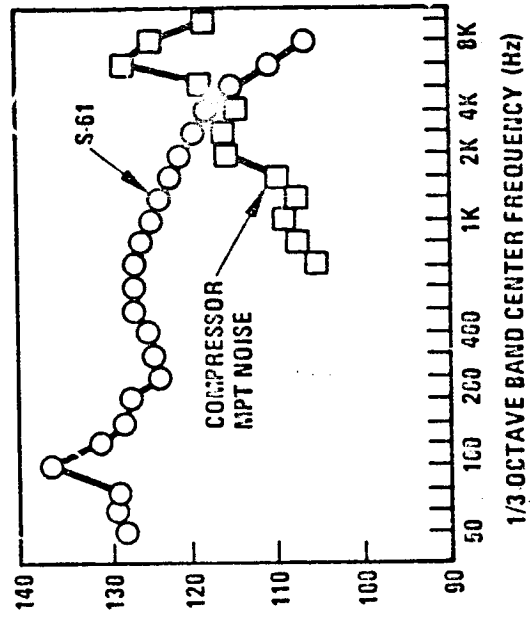
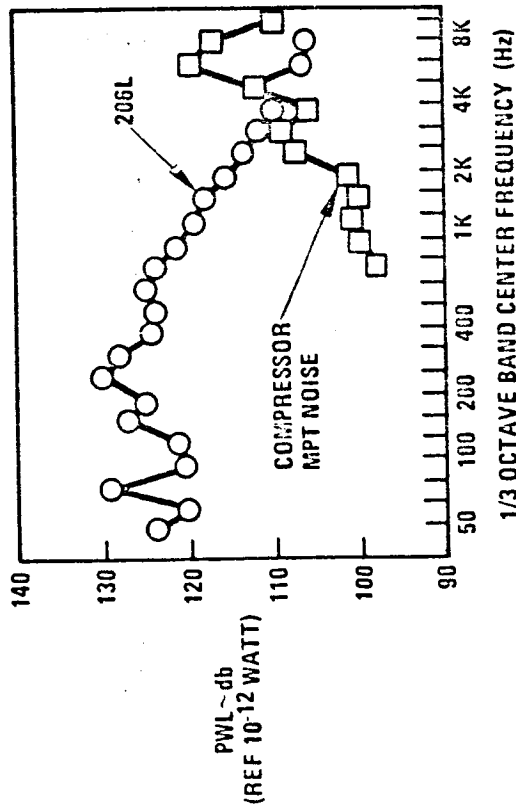
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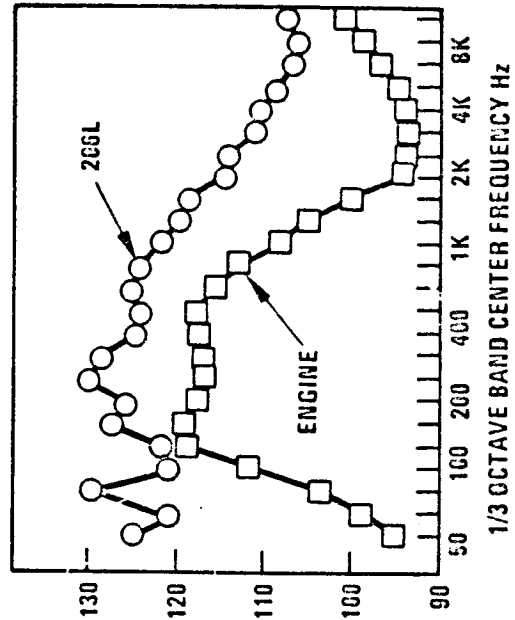
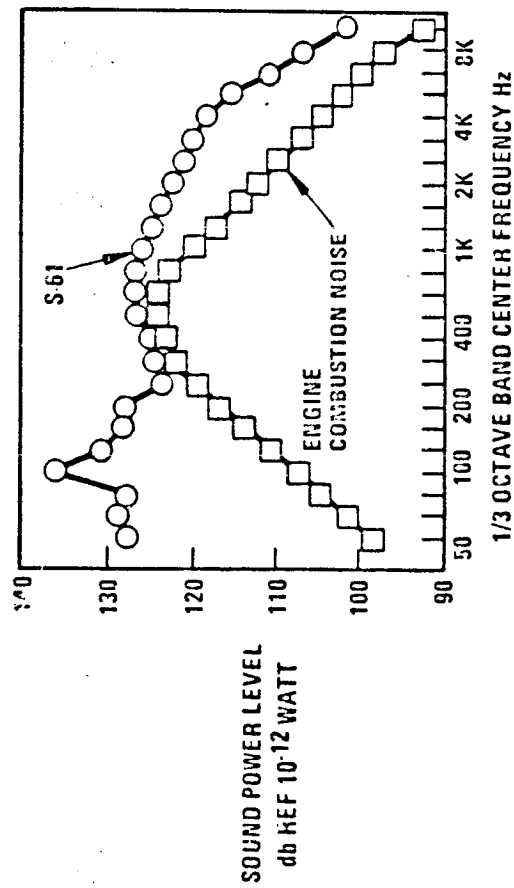


HELICOPTER NOISE TECHNOLOGY ENGINE NOISE EFFECTS ON ROTORCRAFT NOISE REDUCTION





HELICOPTER NOISE TECHNOLOGY COMBUSTION NOISE

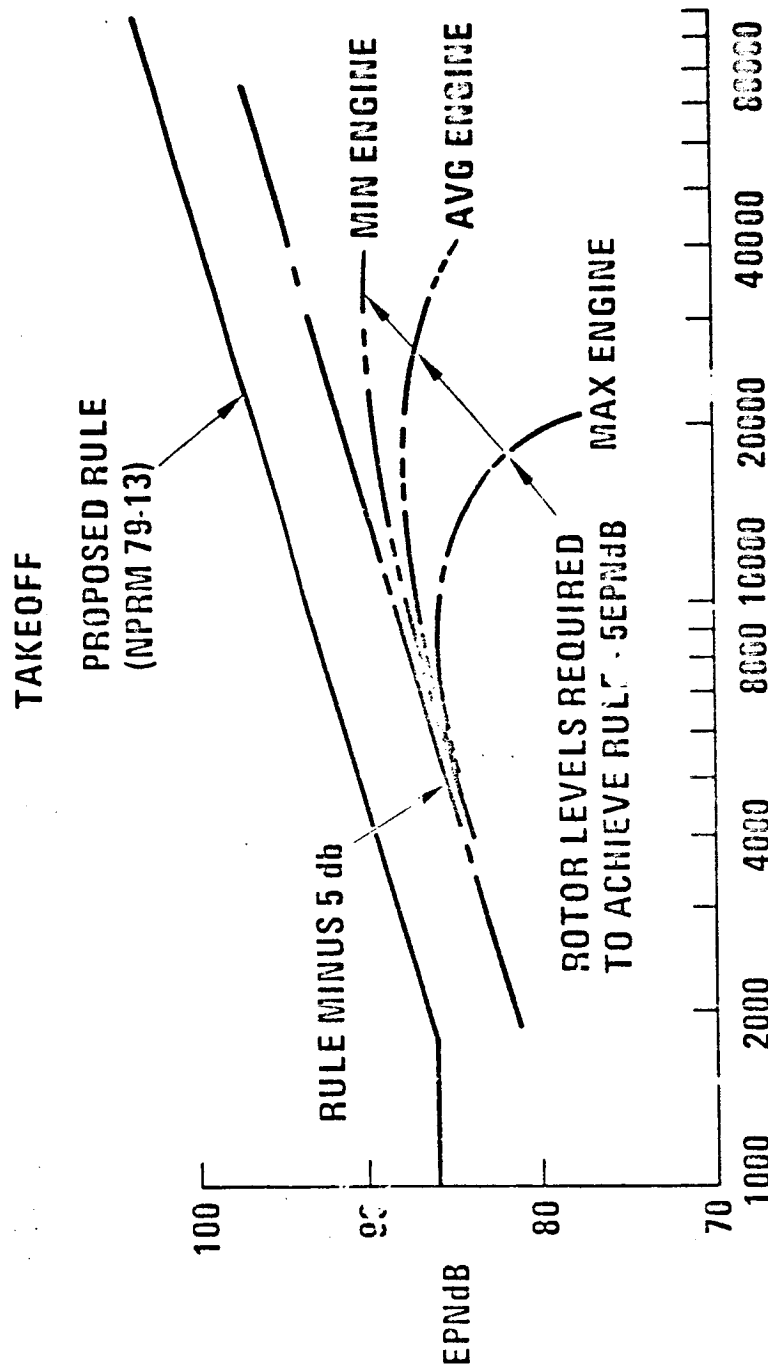


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HELICOPTER NOISE TECHNOLOGY EFFECT OF ENGINE COMBUSTION NOISE ON ROTOR NOISE REDUCTION REQUIRED TO ACHIEVE A ROTOR + ENGINE NOISE LEVEL OF 5EPNdB BELOW RULE



86037-1-17

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HELICOPTER NOISE TECHNOLOGY

SUMMARY — ENGINE NOISE

- ENGINE NOISE WILL LIMIT OR NULLIFY ROTOR NOISE REDUCTIONS
- ENGINE NOISE WILL BE AN OBSTACLE TO THE NOISE CERTIFICATION OF NEW HELICOPTERS
- ENGINE COMBUSTION NOISE REDUCTION SHOULD HAVE HIGH PRIORITY SINCE ITS GENERATION IS NOT UNDERSTOOD AND CANNOT BE CONTROLLED BY CYCLE SELECTION OR DESIGN
- TURBOSHAFT COMPRESSOR NOISE REDUCTION PRESENTS SUBSTANTIAL PROBLEMS NOT ENCOUNTERED BY TURBOFANS. BOTH CENTRIFUGAL AND AXIAL MUST BE CONSIDERED
- ENGINE CASE AND GEAR NOISE REDUCTION IS REQUIRED FOR LOW CABIN NOISE

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INDUSTRY CONCERNS

- FEDERAL REGULATION OF HELIPORT NOISE
 - TRADEOFFS
 - SIZE OF HELICOPTER
 - NUMBER OF OPERATIONS
 - NOISE ABATEMENT PROCEDURES
 - COMMUNITY RELATED FACTORS
 - AMBIENT NOISE
 - AVAILABLE BUFFER ZONES
 - HELIPORT SIZE/CLEAR AREA REQUIREMENTS
 - ASSESSMENT OF ENVIRONMENTAL BENEFITS

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HELICOPTER NOISE TECHNOLOGY

HELIPORT NOISE

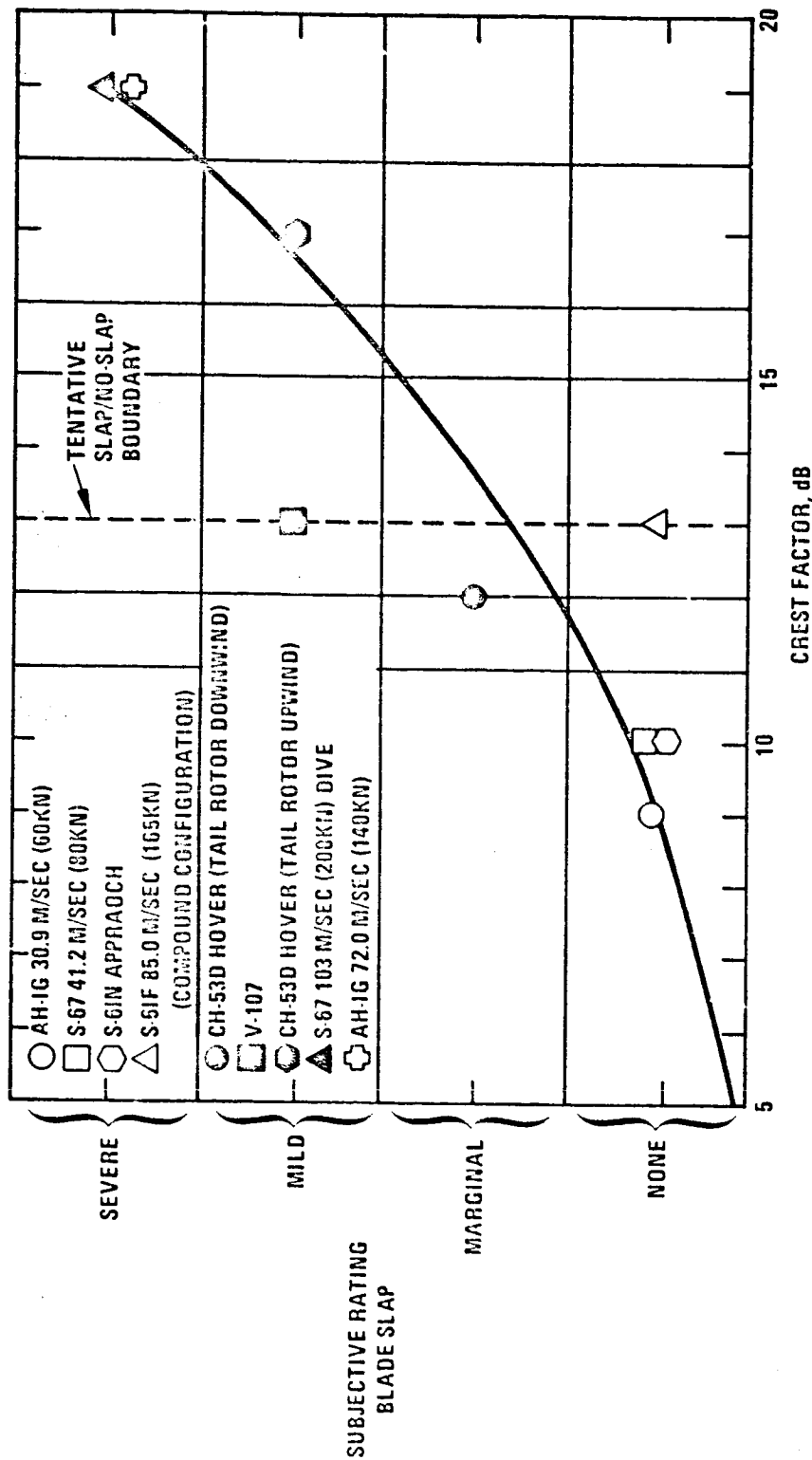
- CURRENT DESCRIPTOR ACCURACY IS QUESTIONABLE FOR HELICOPTER NOISE
- PROPOSED CRITERIA COULD PENALIZE OPERATORS WITH DOUBTFUL GAINS FOR THE COMMUNITY
- CURRENT FOOTPRINT METHODOLOGY INACCURATE
 - DIRECTIVITY IMPORTANT — UNLIKE FIXED WING
 - DATA BASE MARGINAL AT BEST IN QUALITY
 - DATA BASE INCOMPLETE
- ECONOMIC IMPACT NOT YET EVALUATED

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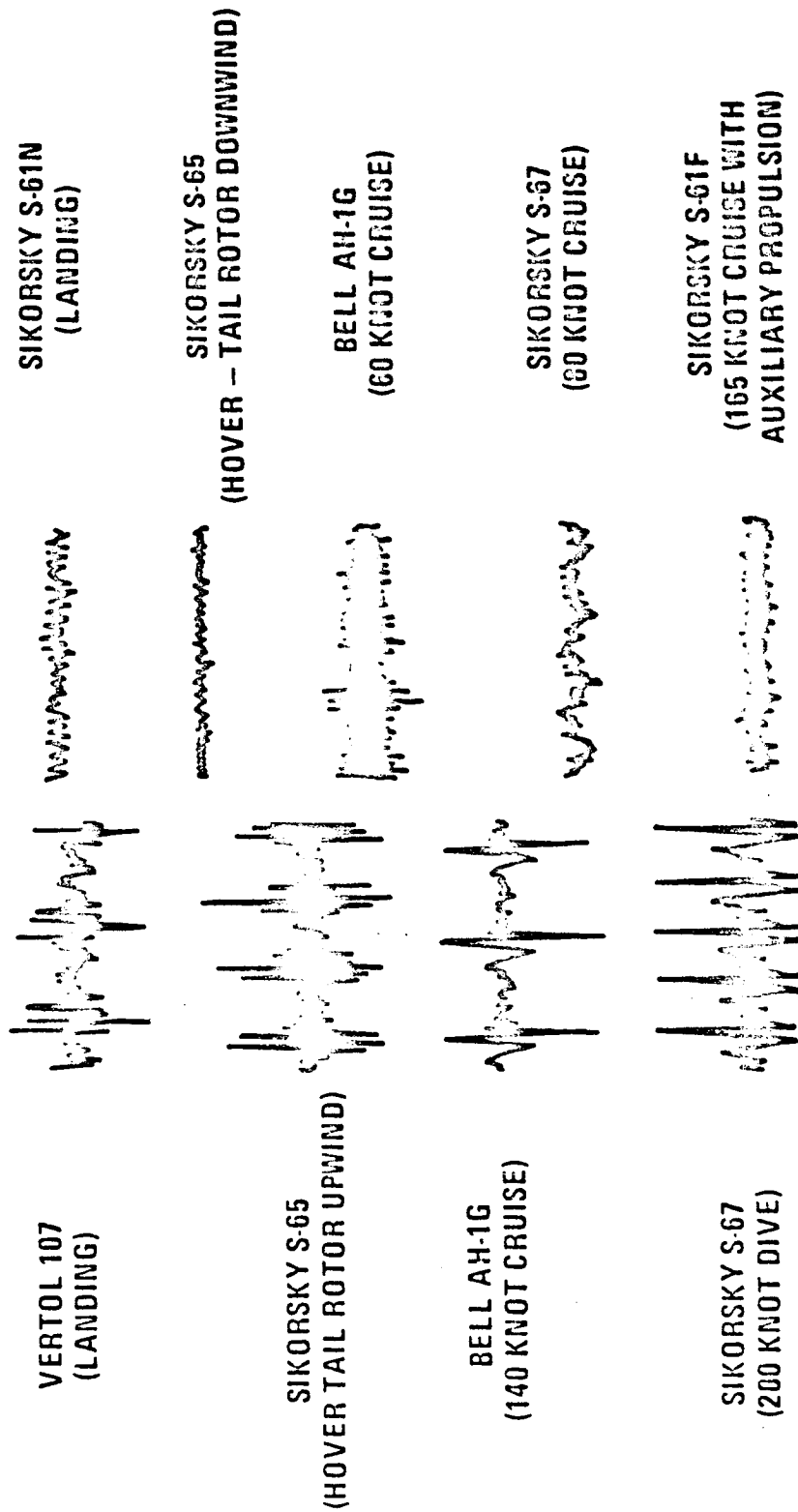


BLADE SLAP ANNOYANCE AS A FUNCTION OF CREST FACTOR



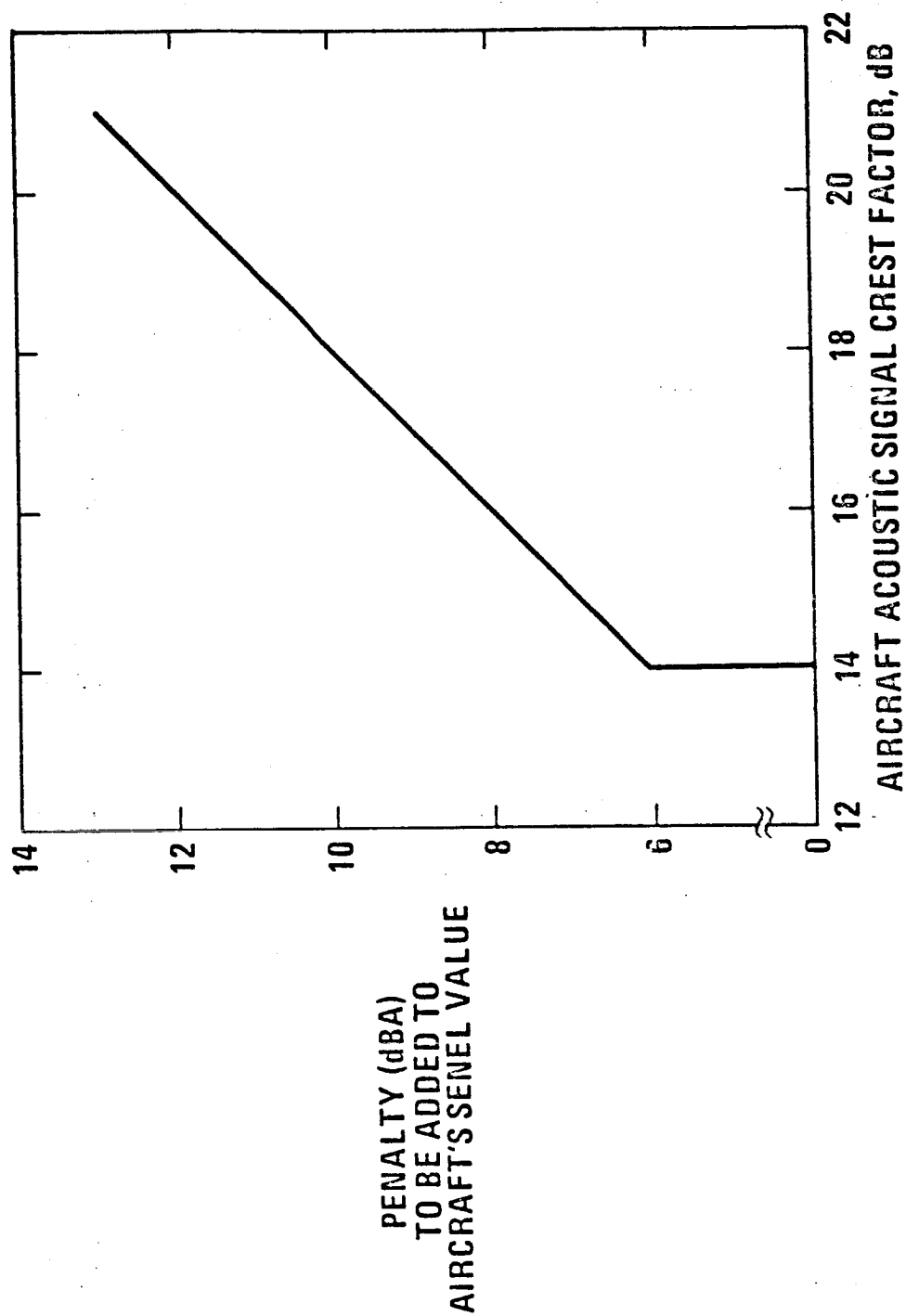


HELICOPTER NOISE TECHNOLOGY IMPULSIVE AND NON-IMPULSIVE HELICOPTER NOISE SIGNATURES





HELICOPTER NOISE TECHNOLOGY BLADE SLAP ANNOYANCE PENALTY



111-189

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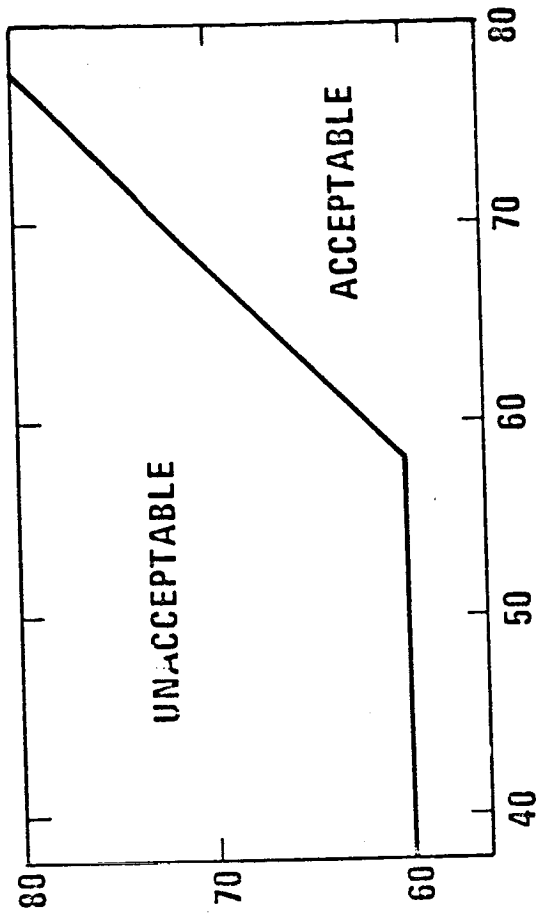
Hughes Helicopters



HELICOPTER NOISE TECHNOLOGY

PROPOSED COMMUNITY NOISE CRITERIA

$L_{dn} - dB(A)$ REF: 0.0002 μbar

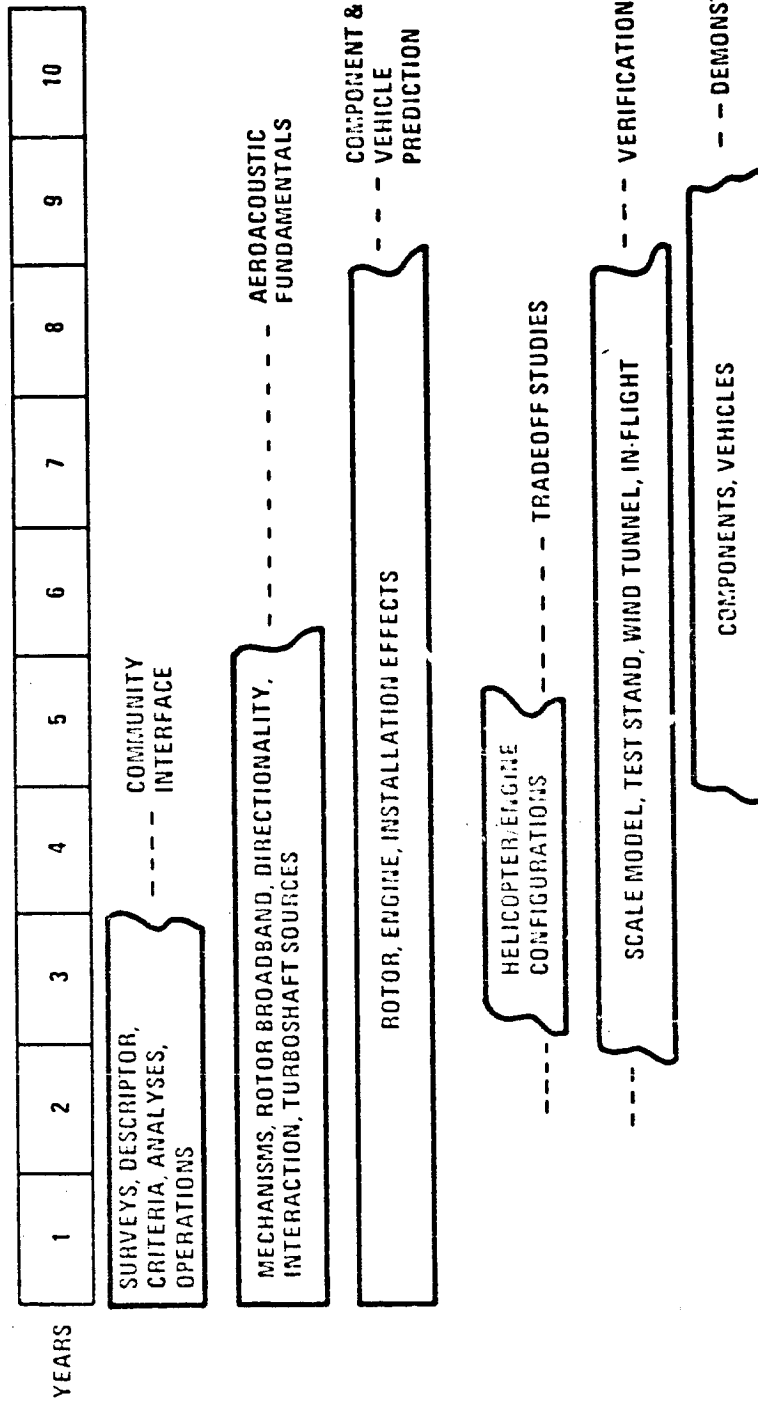


AMBIENT SOUND PRESSURE LEVEL - dB(A) REF: 0.0002 μbar



HELICOPTER NOISE TECHNOLOGY

PROGRAM PLAN — EXTERNAL NOISE



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HELICOPTER NOISE TECHNOLOGY EXTERNAL NOISE

PRIORITIES (In Order of Decreasing Importance)

- PERFORM TRADEOFF STUDIES TO DETERMINE THE NOISE/COST PAYOFFS OF ADVANCED HELICOPTER NOISE TECHNOLOGY
- DEFINE MECHANISMS AND MEANS FOR CONTROLLING MAIN ROTOR BROADBAND NOISE IN FORWARD FLIGHT
- DEFINE MECHANISMS AND MEANS FOR CONTROLLING ROTOR INTERACTION NOISE
 - A) INTRA ROTOR (MAIN)
 - 1) MAIN-TAIL (SINGLE ROTOR)
 - 2) MAIN-MAIN (TANDEM ROTOR)
 - B) INTER ROTOR
- DEFINE A $\Delta SA (L_{dn})$ RELATED DESCRIPTION FOR HELICOPTER NOISE ANNOYANCE WHICH ACCOUNTS FOR THE DIFFERENCES BETWEEN INDIVIDUAL MODELS
- DEFINE MECHANISMS AND MEANS FOR CONTROLLING TURBOSHAFT ENGINE COMBUSTION NOISE

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HELICOPTER NOISE TECHNOLOGY EXTERNAL NOISE

ITEM

DEFINE THE MECHANISMS AND MEANS FOR CONTROLLING MAIN ROTOR BROADBAND NOISE IN FORWARD FLIGHT

MILESTONES/PROGRAMS

- MEASURE MAIN ROTOR BROADBAND NOISE MAGNITUDE AND DIRECTIVITY IN FORWARD FLIGHT (TAKEOFF, APPROACH, CRUISE) WITH AN ACCURACY OF ± 1.0 dB FOR A SMALL AND A LARGE HELICOPTER OVER A RANGE OF TIP SPEEDS AND WITH ROTORS DIFFERING IN NUMBER OF BLADES, TWIST, SWEEP, AND TIP SHAPE. 1985
- IDENTIFY AND/OR FORMULATE ANALYTICAL MODELS TO ROTOR BROADBAND NOISE GENERATION. 1985
- CORRELATE TEST DATA AND MODELS AND IDENTIFY A MEANS OF PREDICTING ROTOR BROADBAND NOISE WITH AN ACCURACY OF ± 1 dB. 1985
- DESIGN AND DEVELOP A LOW BROADBAND (AND DISCRETE FREQUENCY) NOISE ROTOR AND DEMONSTRATE ITS PERFORMANCE. 1989

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HELICOPTER NOISE TECHNOLOGY EXTERNAL NOISE

ITEM

DEFINE MECHANISMS AND MEANS FOR CONTROLLING ROTOR
INTERACTION NOISE

MILESTONES/PROGRAMS

- MEASURE INTRA-ROTOR AND INTER-ROTOR INTERACTION NOISE POWER AND DIRECTIVITY IN FORWARD FLIGHT (TAKEOFF, APPROACH, CRUISE) WITH AN ACCURACY OF ± 1.0 dB FOR SMALL AND LARGE SINGLE ROTOR HELICOPTERS, TANDEM AND COAXIAL HELICOPTERS OVER A RANGE OF TIP SPEEDS AND WITH ROTORS DIFFERING IN NUMBER OF BLADES, TWIST, SWEEP AND TIP SHAPE. 1985
- IDENTIFY AND/OR FORMULATE AEROACOUSTIC MODELS OF ROTOR INTERACTION NOISE IN VARYING DEGREES OF AERODYNAMIC LOADING SOPHISTICATION. 1985
- IDENTIFY THE AEROACOUSTIC MODEL(S) WHICH PREDICT(S) INTERACTION NOISE SPECTRAL INFORMATION WITH ± 3 dB (± 1 dBA). 1986
- EXERCISE THE PREDICTION/CONTROL METHOD BY MAKING DESIGN CHANGES TO A SMALL AND A LARGE HELICOPTER TO MAKE SIGNIFICANT NOISE REDUCTIONS AND DEMONSTRATE. 1988
- DEMONSTRATE NO-INTERACTION NOISE HELICOPTER USING NOTAR (NO TAIL ROTOR) CONCEPT AND COAXIAL (ABC) HELICOPTERS.

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111-194

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HELICOPTER NOISE TECHNOLOGY EXTERNAL NOISE

ITEM

DEFINE A dBA (L_{dn}) RELATED DESCRIPTOR FOR HELICOPTER NOISE ANNOYANCE WHICH ACCOUNTS FOR THE DIFFERENCES BETWEEN INDIVIDUAL MODELS.

MILESTONES/PROGRAMS

- PERFORM PSYCHOACOUSTIC TESTING USING BROADBAND NOISE REFERENCE AND NASA/FAA HELICOPTER NOISE DATA BASES TO DEFINE CORRECTIONS TO THE dBA AND PNL METRICS TO ACCOUNT FOR THE CHARACTER OF HELICOPTER NOISE. 1983
- PERFORM OUTDOOR TESTING WITH SOUND JURY AND A VARIETY OF HELICOPTERS TO VERIFY THE ACCURACY OF THE HELICOPTER NOISE CORRECTION. 1983
- PERFORM COMMUNITY NOISE SURVEYS AT CONCENTRATED HELICOPTER TRAFFIC AREAS TO FURTHER VERIFY THE HELICOPTER NOISE CORRECTION. 1985
- DEFINE NOISE ABATEMENT PROCEDURES FOR MINIMIZING THE ANNOYANCE OF HELICOPTER TAKEOFF, LANDING AND MANEUVER OPERATIONS. 1986
- ACQUIRE AN EXTERNAL NOISE DATA BASE FOR CURRENT COMMERCIAL HELICOPTERS. 1985
- DEFINE SENEL CONTOURS FOR CURRENT COMMERCIAL HELICOPTERS AND PREPARE MANUAL FOR PREDICTING L_{dn} CONTOURS. 1987

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HELICOPTER NOISE TECHNOLOGY

EXTERNAL NOISE

ITEM

DEFINE MECHANISMS AND MEANS FOR CONTROLLING TURBOSHAFT ENGINE COMBUSTION NOISE

MILESTONES/PROGRAMS

- PERFORM TESTING TO DEFINE LARGE AND SMALL ENGINE TURBOSHAFT COMBUSTION SOUND POWER FOR A VARIETY OF CONFIGURATIONS. 1983
- IDENTIFY AND/OR FORMULATE ANALYTICAL MODELS OF COMBUSTION SOUND POWER GENERATION. 1983
- CORRELATE TEST DATA AND MODELS TO IDENTIFY A MEANS OF PREDICTING TURBOSHAFT COMBUSTION SOUND POWER WITH AN ACCURACY OF ± 1.0 dB. 1984
- PERFORM TESTING TO DEFINE CASE RADIATED VERSUS EXHAUST RADIATED COMBUSTION NOISE AND INSTALLATION EFFECTS ON DIRECTIVITY. 1986
- DEVELOP SILENCING DESIGN GUIDE FOR MID FREQUENCY EXHAUST ATTENUATION OF TURBOSHAFT ENGINES. 1988

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HELICOPTER NOISE TECHNOLOGY

EXTERNAL NOISE

ITEM

VERIFY AND DEMONSTRATE THE NEWLY DEVELOPED HELICOPTER NOISE REDUCTION TECHNOLOGY

MILESTONES/PROGRAMS

- DEMONSTRATE LOW MAIN ROTOR NOISE USING A SILENCED NOTAR ANTI TORQUE SYSTEM. 1986
- DEMONSTRATE A LOW NOISE TWO SPEED ROTOR HELICOPTER (LOW SPEED FOR TERMINAL OPERATIONS AND HIGH SPEED FOR CRUISE). 1983
- DEMONSTRATE A LOW NOISE HELICOPTER WITH A TAIL ROTOR SYSTEM THAT EXHIBITS NO AUDIBLE HARMONIC NOISE IN TAKEOFF, APPROACH OR CRUISE. 1989

8003/1 31

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HELICOPTER NOISE TECHNOLOGY EXTERNAL NOISE

ITEM

PERFORM TRADEOFF STUDIES TO DETERMINE THE ECONOMICS OF
APPLYING NEW ROTOR AND ENGINE NOISE REDUCTION TECHNOLOGY

MILESTONES/PROGRAMS

- DETERMINE THE NOISE/COST TRADEOFF OF APPLYING EXISTING
NEW ROTOR TECHNOLOGY (OGEE TIP, ETC.)
- DETERMINE THE TRADEOFF BETWEEN POPULATION EXPOSED TO
OVER 65 L_{dn} NOISE AND COSTS TO REDUCING HELICOPTER FLEET
NOISE LEVELS (MAINTAINING PERFORMANCE) FOR NEW DESIGNS
AND FOR IN-PRODUCTION HELICOPTERS
- DETERMINE THE NOISE/COST/PERFORMANCE TRADEOFFS FOR
VARIABLE SPEED ROTOR SYSTEMS

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HELICOPTER NOISE TECHNOLOGY INTERNAL NOISE CONCERNS

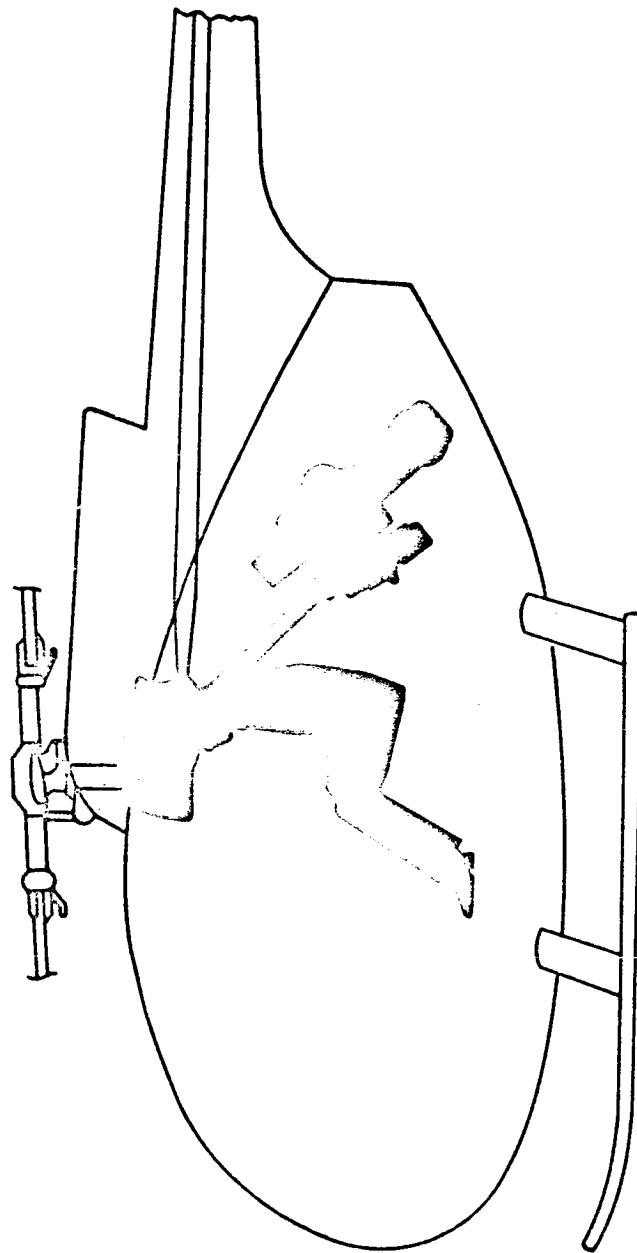
- CRITERIA HAVE NOT BEEN ESTABLISHED FOR COMMERCIAL HELICOPTER INTERNAL NOISE
 - SPEECH COMMUNICATION
 - ANNOYANCE
- PREDICTION ACCURACY IS POOR
- UNTREATED NOISE LEVELS GROW WITH EACH SUCCEEDING GENERATION
- USE OF "SOUNDPROOFING" ALONE IS UNECONOMICAL

800371-33

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HELICOPTER NOISE TECHNOLOGY RELATIVE LOCATION OF NOISE SOURCES



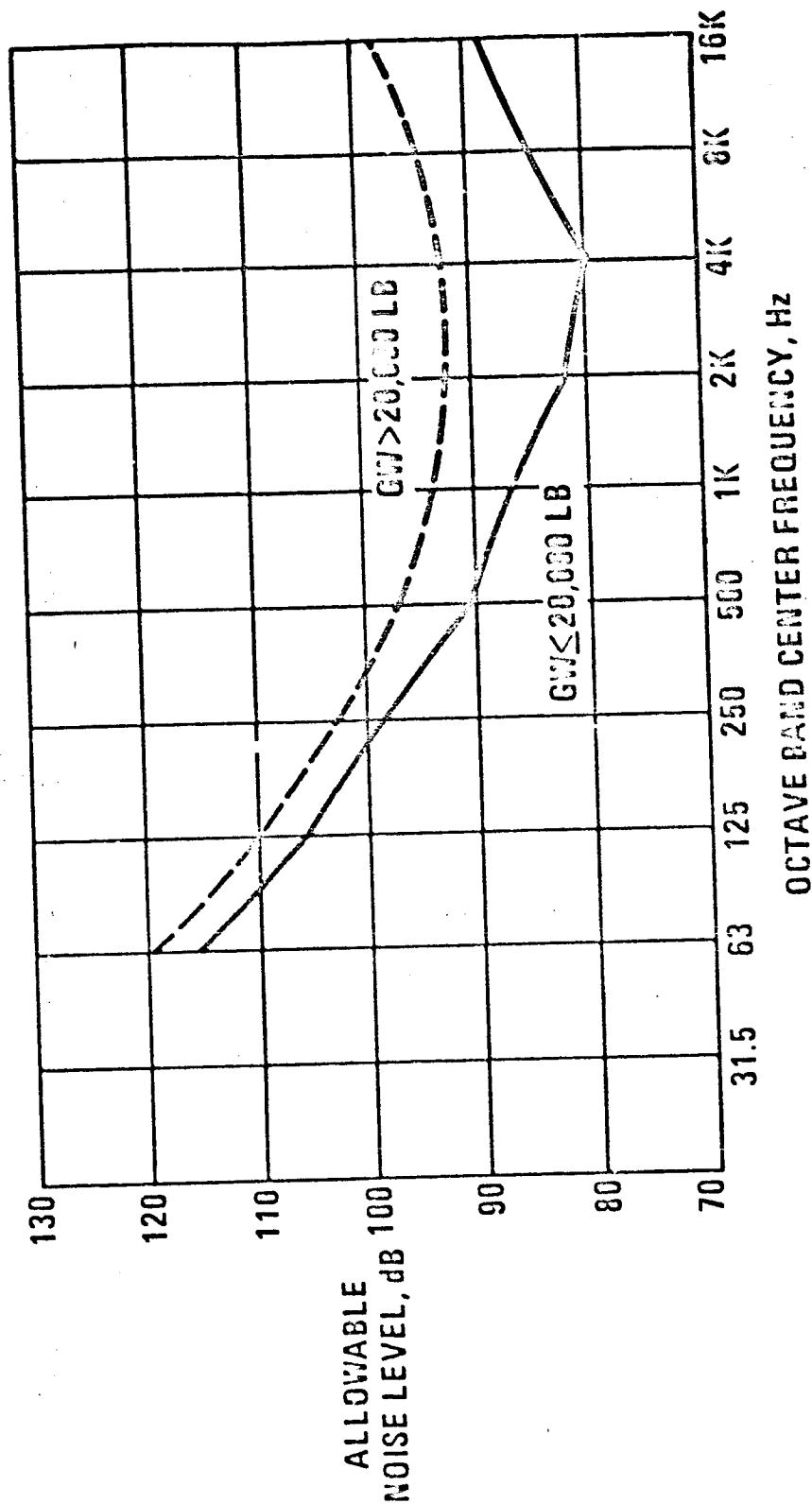
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HELICOPTER NOISE TECHNOLOGY PROPOSED NOISE LIMITS INSIDE MILITARY HELICOPTERS



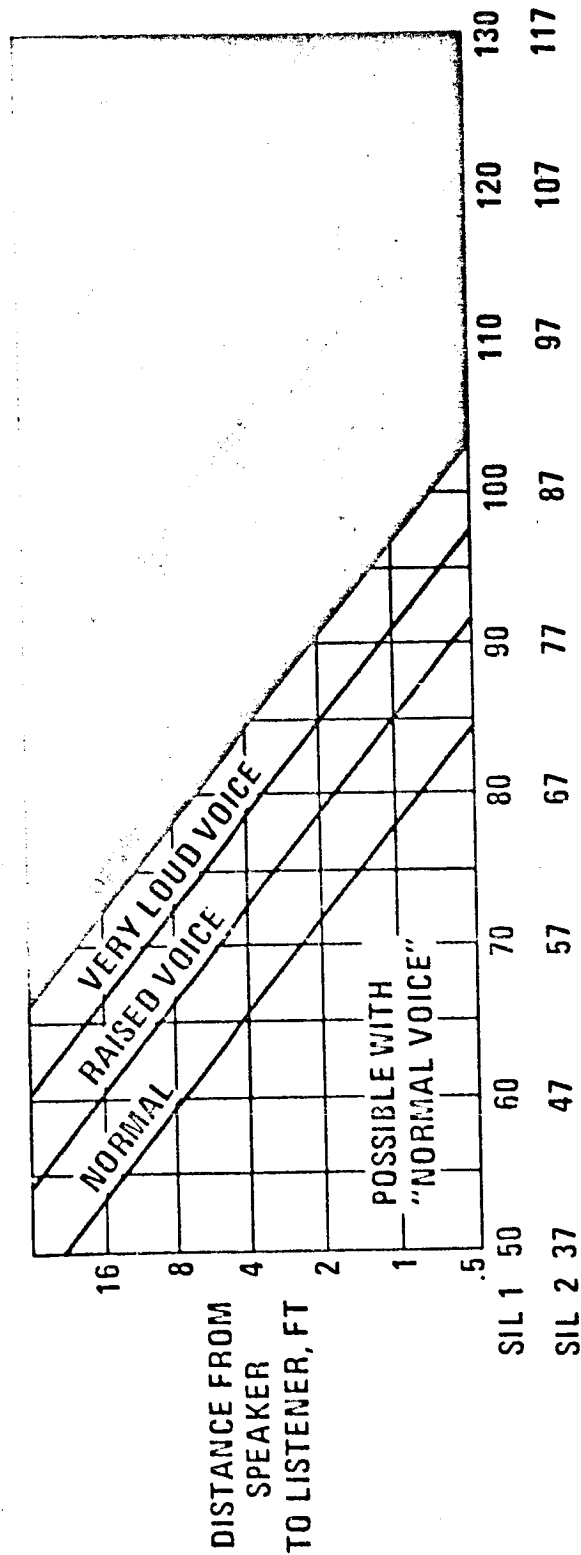
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HELICOPTER NOISE TECHNOLOGY SPEECH INTERFERENCE LEVEL



- 1 SCALE ADJUSTED FOR HELICOPTER TYPE BACKGROUND NOISE
- 2 SCALE BASED ON BROADBAND BACKGROUND NOISE (J.C. WEBSTER)

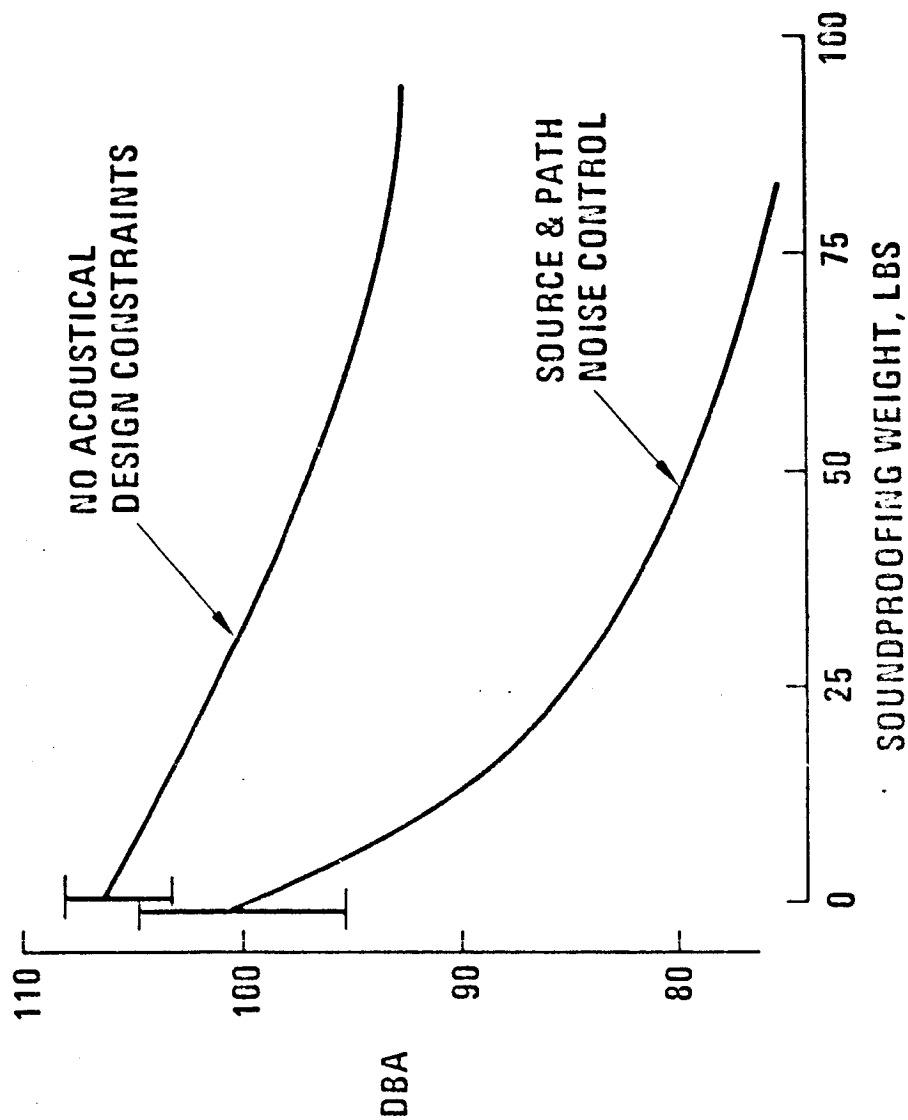
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HELICOPTER NOISE TECHNOLOGY

SOUNDPROOFING EFFICIENCY



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HELICOPTER NOISE TECHNOLOGY PROGRAM PLAN — INTERNAL NOISE

YEARS	1	2	3	4	5	6	7	8	9	10
-------	---	---	---	---	---	---	---	---	---	----

SPEECH, CRITERIA,
ANNOYANCE CRITERIA

PASSENGER/CREW
ACCEPTANCE

SOURCE GENERATION AND RADIATION, ISOLATION,
STRUCTURES, MATERIALS, RECEIVING SPACE

PREDICTION &
VERIFICATION

COMPONENT DEVELOPMENTS,
OPTIMIZATION, DEMONSTRATION

NOISE CONTROL



HELICOPTER NOISE TECHNOLOGY INTERNAL NOISE

PRIORITIES (In Order of Decreasing Importance)

- DEFINE MECHANISMS AND MEANS FOR CONTROLLING MAIN TRANSMISSION GEAR MESH HARMONIC NOISE
- DEVELOP METHODOLOGY FOR INTERRUPTING THE FLOW OF GEARBOX VIBRATORY MOTION FROM THE MESH POINT TO AIRFRAME RADIATING STRUCTURE
- DEFINE THE RELATIONSHIP BETWEEN HELICOPTER NOISE SPECTRAL CONTENT, SPEECH COMMUNICATION, AND ANNOYANCE
- PERFORM NOISE REDUCTION COMPONENT DEVELOPMENT AND DEMONSTRATE

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HELICOPTER NOISE TECHNOLOGY INTERNAL NOISE

ITEM

DEFINE MECHANISMS AND MEANS FOR CONTROLLING MAIN TRANSMISSION GEAR
MESH HARMONIC NOISE

MILESTONES/PROGRAMS

- USE EXISTING ANALYSES TO DESIGN GEAR PAIRS WITH 5 dB REDUCTION AT
MESH FREQUENCY AND HARMONICS AND DEMONSTRATE. 1984
- REDESIGN GEARS IN AN EXISTING HELICOPTER TRANSMISSION FOR 5 dB NOISE
REDUCTION AND DEMONSTRATE. 1986
- DEVELOP MEANS FOR DAMPING TRANSMISSION COMPONENTS INCLUDING
CASINGS TO ATTAIN LOSS FACTOR OF 0.10 WITH NO SUBSTANTIAL DETRIMENT
TO COMPONENT LIFE AND HEAT TRANSFER PROPERTIES AND DEMONSTRATE. 1985
- DEVELOP A METHOD OF PREDICTING CABIN TRANSMISSION NOISE LEVELS TO
WITHIN ± 3 dB IN THE 500 TO 2000 Hz OCTAVE BANDS. 1986

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HELICOPTER NOISE TECHNOLOGY INTERNAL NOISE

ITEM

DEVELOP METHODOLOGY FOR INTERRUPTING THE FLOW OF GEARBOX VIBRATORY MOTION FROM THE MESH POINT TO AIRFRAME RADIATING STRUCTURE

MILESTONES/PROGRAMS

- PERFORM AN ANALYTICAL STUDY, USING EXPERIMENTAL AIRFRAME AND TRANSMISSION IMPEDENCE INFORMATION, TO DETERMINE EFFECTIVE ISOLATION CRITERIA WITH ACCEPTABLE STATIC STIFFNESSES. 1933
- PERFORM EXPERIMENTAL/ANALYTICAL STUDY OF AN EXISTING SUCCESSFUL MAIN TRANSMISSION ISOLATION SYSTEM TO EXTRACT GENERAL PRINCIPLES FOR APPLICATION TO OTHER SYSTEMS. 1935
- DEVELOP CRITERIA FOR DESIGN, BUILD, AND TEST OF A MINIMUM 5 dB NOISE REDUCTION PASSIVE ISOLATION SYSTEM FOR A SMALL AND A LARGE HELICOPTER. 1938

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INTERNAL NOISE

ITEM

DEFINE THE RELATIONSHIP BETWEEN HELICOPTER NOISE SPECTRAL CONTENT, SPEECH COMMUNICATION, AND ANNOYANCE

MILESTONES/PROGRAMS

- PERFORM PSYCHOACOUSTIC TESTING TO DETERMINE SPEECH INTELLIGIBILITY IN HELICOPTER NOISE ENVIRONMENTS AND METHODS FOR COMPUTING IT. 1984
- PERFORM PSYCHOACOUSTIC TESTING TO DETERMINE ANNOYANCE IN HELICOPTER NOISE ENVIRONMENTS AND METHODS FOR COMPUTING IT. 1984
- PERFORM OPINION SURVEYS ON EXISTING HELICOPTERS TO VERIFY THE ANNOYANCE CRITERIA DEVELOPED. 1986

800371-42

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HELICOPTER NOISE TECHNOLOGY INTERNAL NOISE

ITEM

PERFORM NOISE REDUCTION COMPONENT DEVELOPMENT AND DEMONSTRATE

MILESTONES/PROGRAMS

- DEVELOP HYDRAULIC COMPONENT PULSE DAMPENING AND ISOLATION SYSTEMS PLUS METHODOLOGY FOR APPLICATION. 1984
- DEVELOP BUILT-IN DAMPING MEANS FOR COMPOSITE AIRFRAME AND TRANSMISSION COMPONENTS (DAMPED MATRIX). 1986
- DEVELOP DESIGN CRITERIA FOR THE APPLICATION OF DAMPED SANDWICH PANELS TO AIRCRAFT STRUCTURE. 1983
- DEVELOP SOUNDPROOFING PANEL ISOLATION SYSTEM TO PRODUCE 20 dB SIL ATTENUATION AND ACCEPTABLE STATIC DEFLECTIONS.
- DEVELOP SOUNDPROOFING PANEL SEAL SYSTEMS TO ALLOW NO MORE THAN 0.1% LEAKAGE IN THE SIL FREQUENCY RANGE.
- DEVELOP DAMPING ELASTOMERS WHICH ARE EFFECTIVE IN THE 20 TO 400°F TEMPERATURE RANGE AND IN THE 200 TO 5000 $\frac{1}{2}$ FREQUENCY RANGE.

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HELICOPTER NOISE TECHNOLOGY

INTERNAL NOISE

ITEM

PERFORM TRADEOFF STUDIES TO DETERMINE THE RELATIVE
COST/WEIGHT EFFECTIVENESS OF STRUCTURAL NOISE REDUCTION
AND CONVENTIONAL SOUNDPROOFING

MILESTONES/PROGRAMS

- DETERMINE ANALYTICALLY, FOR SEVERAL CURRENT
SOUNDPROOFED COMMERCIAL HELICOPTERS, THE NET WEIGHT
SAVINGS AVAILABLE THROUGH STRUCTURAL NOISE REDUCTION
AND THE DEVELOPMENT/MANUFACTURING COSTS NECESSARY
TO ACHIEVE THEM. 1983

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HELICOPTER NOISE REQUIREMENTS

WHAT IS NEEDED

- HELICOPTERS THAT ARE LOUD (EXEMPTED FROM FAA REQUIREMENT) FOR REMOTE OPERATIONS IN NON NOISE-SENSITIVE AREAS WITH OUTSTANDING PERFORMANCE AND COST CHARACTERISTICS
- HELICOPTERS THAT ARE REASONABLY QUIET (JUST MEET FAA REQUIREMENT) FOR MODERATELY NOISE-SENSITIVE OPERATIONS WITH GOOD PERFORMANCE AND COST CHARACTERISTICS
- HELICOPTERS THAT ARE VERY QUIET (SUBSTANTIALLY BETTER THAN FAA REQUIREMENT) FOR EXTREMELY NOISE-SENSITIVE AREAS
- TECHNOLOGY TO ATTAIN COMMUNITY NOISE GOALS WHILE SATISFYING USER PERFORMANCE AND COST NEEDS

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William Walls
Boeing Vertol

BOEING R&D AIRPLANE NOISE REDUCTION EXPENDITURES
(MILLIONS OF DOLLARS)

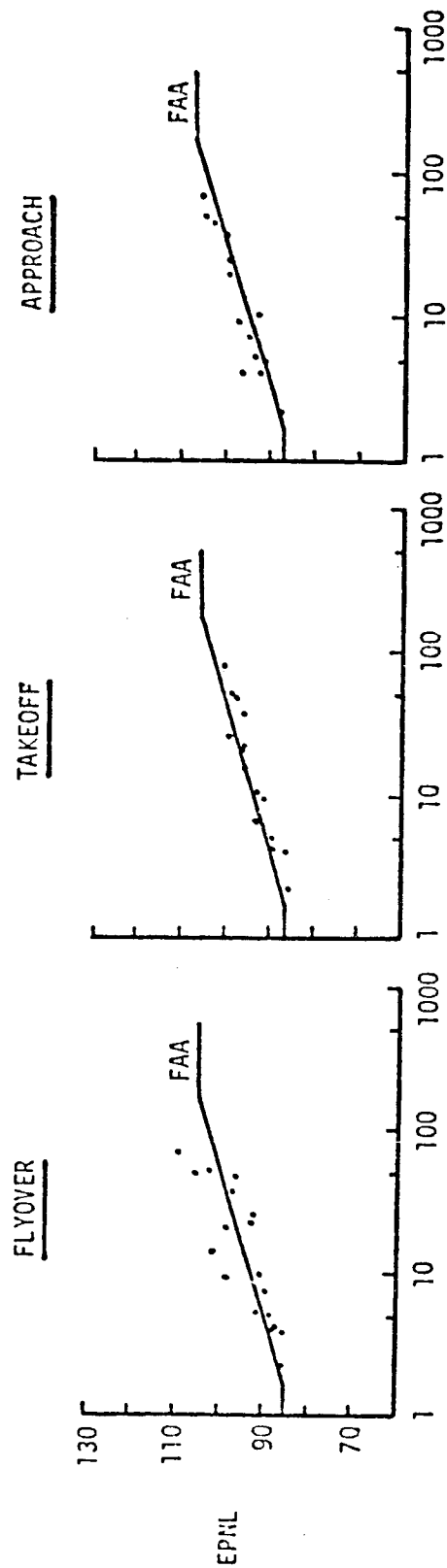
YEAR	BOEING FUNDED	GOVERNMENT FUNDED	TOTAL DOLLARS	AVERAGE YEARLY MANPOWER
1958 THROUGH 1964	2.461	0.322	2.783	
1965	1.384	0.210	1.594	
1966	2.528	0.925	3.453	
1967	3.197	3.464	6.661	352
1968	10.957	6.878	17.835	746
1969	8.508	2.873	11.381	746
1970	4.447	1.082	5.529	296
1971	3.594	5.788	9.382	338
1972	6.031	10.918	16.949	635
1973	9.668	9.639	19.303	592
1974	5.866	8.049	13.915	454
1975	7.499	3.232	10.731	340
1976	8.584	0.845	9.429	280
1977	11.277	0.569	11.846	303
1978	10.631	0.407	11.038	289
1979	10.088	0.339	10.425	356
TOTAL	106.718	55.536	162.54	
1980 (ESTIMATE)	(13.866)	(0.410)	(14.026)	

NOTE: ABOVE EXPENDITURES DO NOT INCLUDE COSTS FOR SUPPORT OF PRODUCTION AIRPLANE NOISE REDUCTION ACTIVITIES TOTALING OVER 54 MILLION DOLLARS OR CAPITAL EXPENDITURES FOR ACOUSTIC TEST FACILITIES TOTALING OVER 18 MILLION DOLLARS.

2-29-80

Airplane manufacturers have invested heavily in noise research programs for many years, endeavoring to develop viable schemes that would reduce airplane noise. Boeing alone has averaged over 430 engineers, technicians, and skilled laborers working on noise-related activities during the past 13 years. Since 1958, expenditures on noise research have exceeded \$160 million. This does not include some \$18 million expended on sophisticated acoustic test facilities, or over \$54 million for putting the research results into practice on production airplanes.

PROPOSED FAA ROTORCRAFT NOISE RULES



WEIGHT ~ LBS X 1000

PANEL DISCUSSION

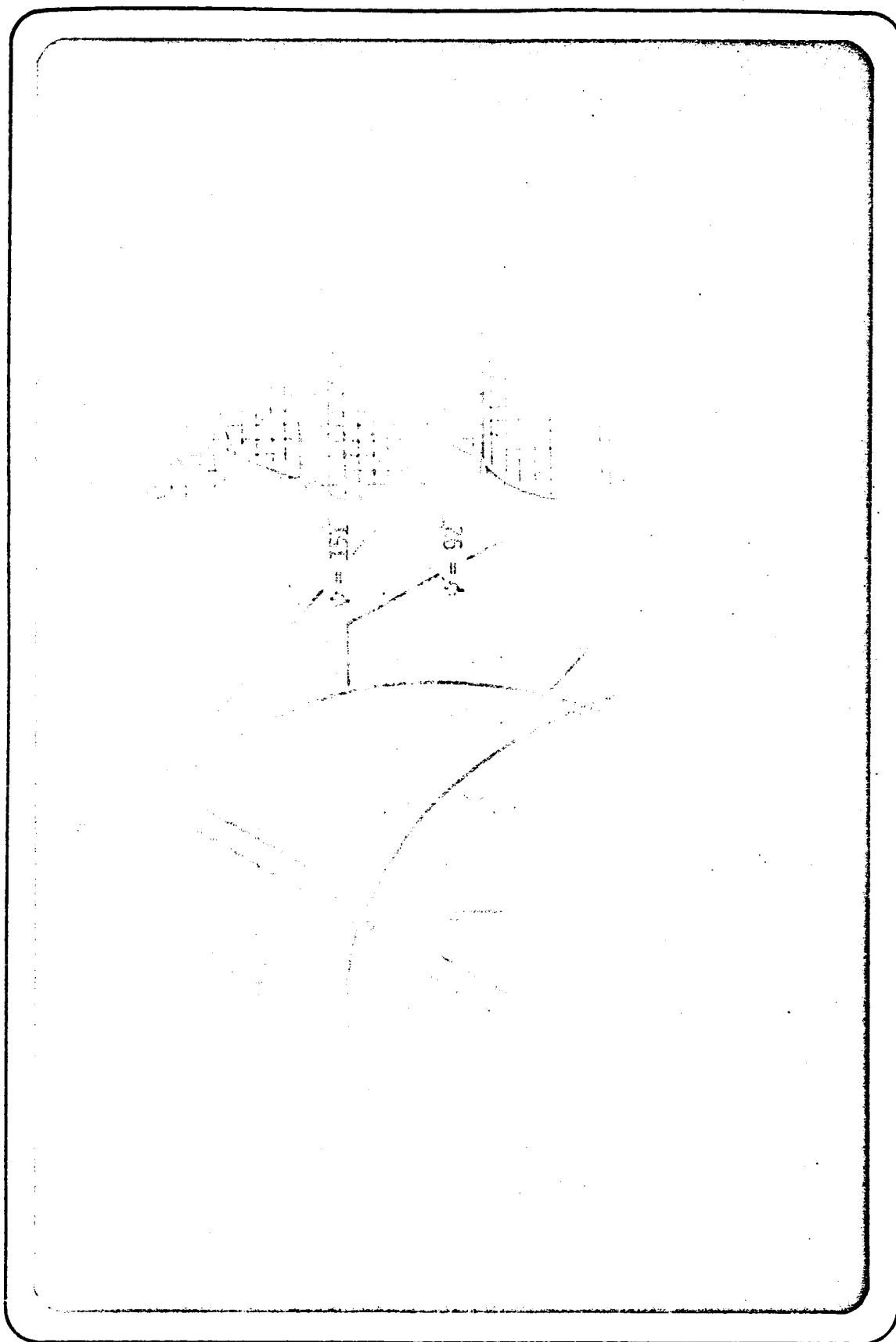
By

C. R. Cox

CHIEF OF ACOUSTICS

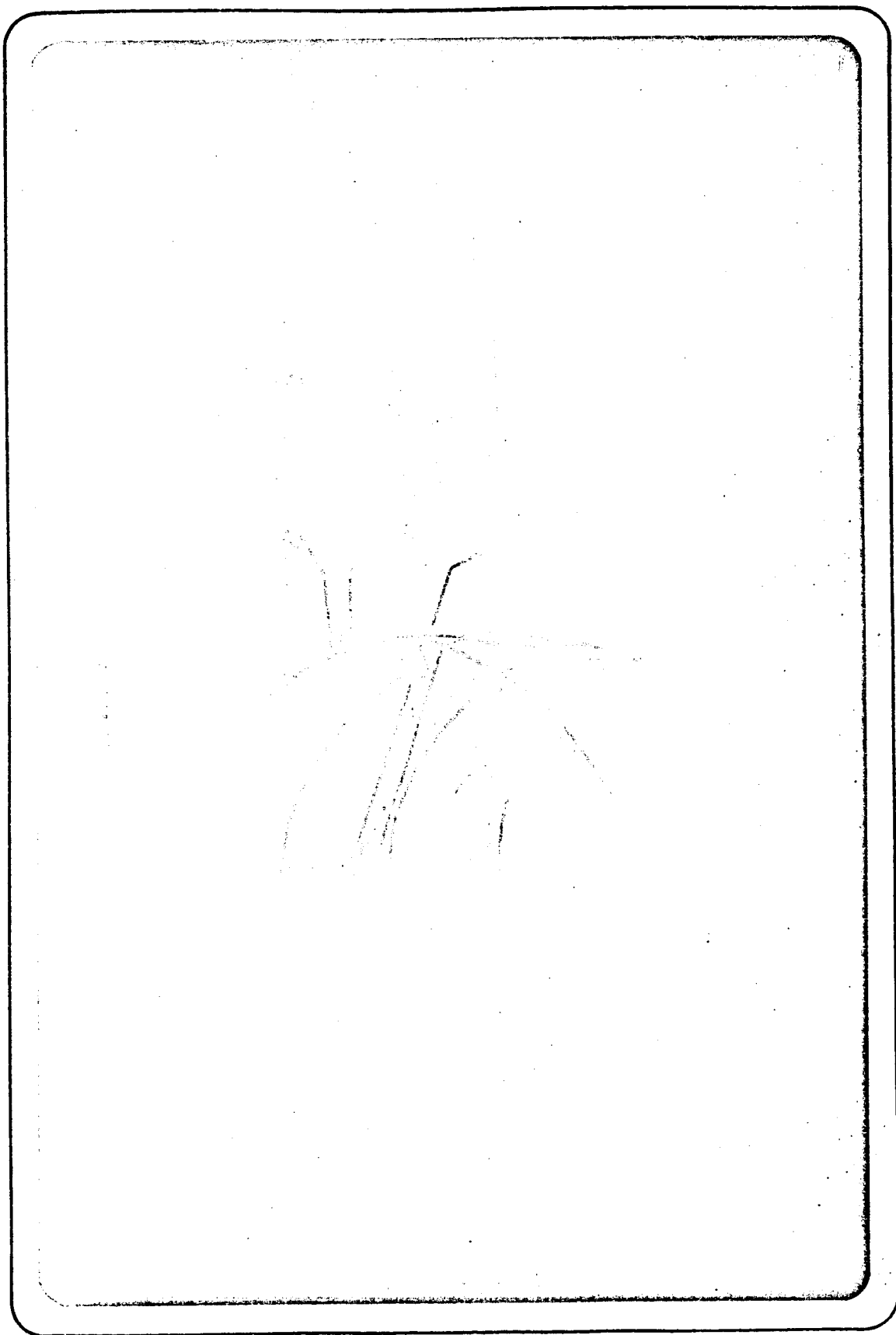
BELL HELICOPTER TEXTRON

Helicopter noise generation is directly related to the aerodynamic behavior of the rotor systems. The aeroacoustic mechanisms are complex. Different mechanisms dominate for main and tail rotors and their dominance is a function of both design parameters and operating conditions. Schlieren photographs of a small scale rotor illustrate the shock formation at high speeds, the axial location of potential intersections between the wake and the advancing blade, and possible shocks created by one of these intersections. Such illustrations indicate the varying degree of aerodynamic information required to model and predict each acoustic event. Measured airload fluctuations along the span of a full-scale blade caused by blade/wake intersections are shown in the last illustration.



111-216

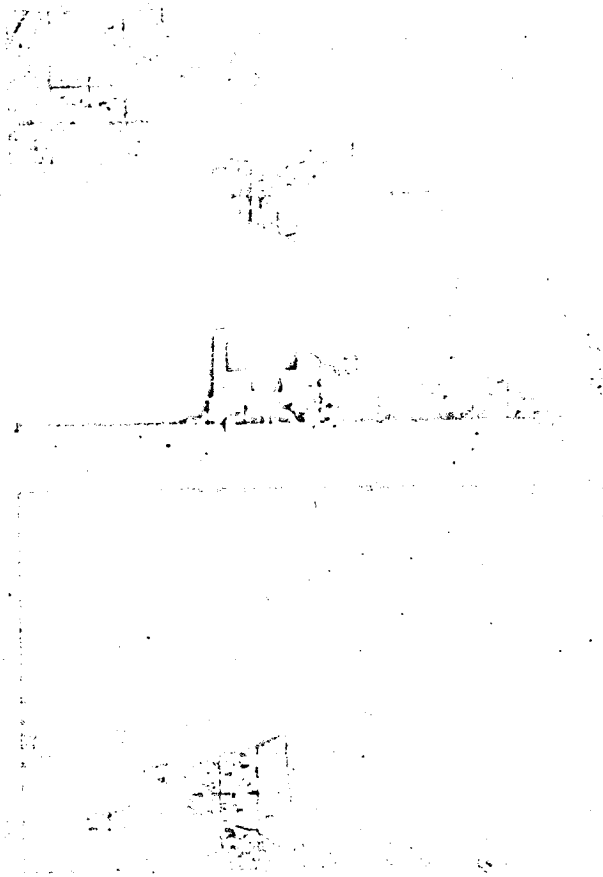
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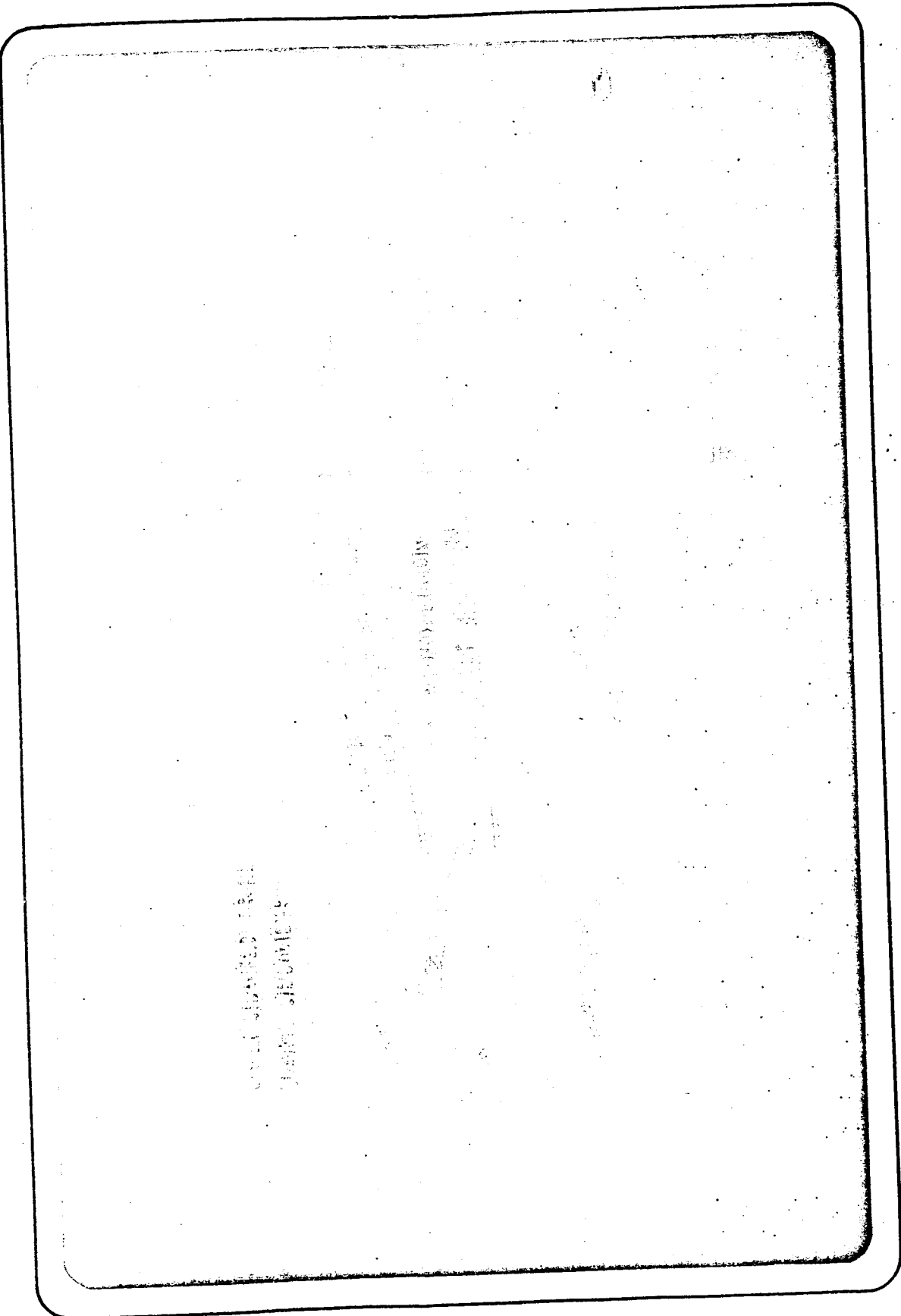


111-217 BLACK AND WHITE PHOTOGRAPH

SHOCK REDUCED ON ADVANCED
BY 1-1/2 REVOLUTION OLD

DESCENT RATE = 500 - 600 FPM





D. S. Jenney, Sikorsky

1. A first-principles analysis is needed, and it must be well correlated with reliable test data. Building a reliable data base is an important part of the task where NASA might work with FAA on test techniques and actual data gathering. It's important that we not oversell our capability, and thereby minimize the magnitude of the task.
2. A wind tunnel capability to measure noise is needed. This should be planned for the 40' x 80' modification, and perhaps modeled ahead of time at smaller scale, to be sure it will work.
3. NASA may be able to help invent and demonstrate noise reduction techniques - new tips, quiet tail rotors, internal dampening materials.
4. Fundamental work is needed on noise descriptors, (Psychoacoustics). Community noise requirements must be reduced to measureable, not emotional requirements.

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Acoustics Session - Discussion

- . To some degree, rotor improvements to reduce noise will also improve performance, so in effect, the reduced noise is free. At some point, the benefits achievable this way run out, and a price must be paid. Today's quieter rotors are probably near that point, but no one knows just where that point is.
- . Tail rotor noise is also important, but it's not on NASA's near-term plans.
- . Rotor noise efforts must consider both blade loading effects and off-blade transonic effects. Each requires good knowledge of airflow environment around the rotor.

Vibrations Panel

Chairman and Keynote - Troy Gaffey, Bell

William White - U.S. Army

E. Robert Wood - Hughes

David Jenney - Sikorsky

William Walls - Boeing Vertol

Discussion

VIBRATION TECHNOLOGY OVERVIEW

TROY GAFFEY

MANAGER, FLIGHT TECHNOLOGY

BELL HELICOPTER TEXTRON

HAA/NASA ADVANCED ROTOCRAFT
TECHNOLOGY WORKSHOP

HAA/NASA ADVANCED ROTORCRAFT TECHNOLOGY WORKSHOP

ABSTRACT OF VIBRATION TECHNOLOGY OVERVIEW

Troy M. Gaffey

Rotorcraft vibration control has long been recognized as a challenging technical problem involving coupling of rotorcraft aerodynamics and dynamics (Fig. 1). The physics of the rotorcraft vibration problem are so complex that it is not yet possible to accurately model the aerodynamic problem or the dynamic problem separately--let alone the coupled dynamics and aerodynamics.

Vibration Control Approaches

There are two approaches used to control rotorcraft vibration; the design approach where one attempts to design for inherent low vibration and the device approach where vibration control devices are added to the rotorcraft specifically for the purpose of controlling vibration (Fig. 2). Although the design approach has been used for many years, design technology is still inadequate to design in inherent low vibration as there is insufficient data available to permit designing rotors for minimal hub forces and moments and airframe dynamic response cannot be accurately predicted. Furthermore, it is now apparent that factors such as the rotor downwash on the airframe and the airframe upwash acting on the rotor are important factors in the rotorcraft vibration problem. Very little data is available with regard to these factors (Fig. 3).

However, the device approach has progressed to the point where highly effective vibration controls are available. Such devices as hub and blade absorbers, pylon isolation schemes and cabin absorbers and isolation can, when used in conjunction with good dynamic design practice, provide a smooth ride at a weight penalty of 2 to 3 percent of gross weight. Of course, these vibration controls do have an adverse effect on operating costs in the sense they require maintenance and repairs or replacement.

Figure 4 is an example of the vibration control devices used on three "3rd generation" civil helicopters. Note that in spite of size or number of blades similar approaches and weight penalties were required to achieve the smooth ride expected of these modern helicopters.

The vibration control devices used on the Bell Model 222 are illustrated in Figure 5. In addition to the Nodal Beam, which isolates the airframe from rotor 2/rev hub forces the 222 uses two other devices. Hub mounted inplane pendular absorbers are used to suppress 3/rev inplane vibration--controlling 4/rev in the fuselage. A 2/rev Frahm absorber is mounted in the nose to control 2/rev lateral vibration resulting from main rotor downwash impacting on the fin. Figure 6 shows measured vibration levels and compares the measured vibration with BHT comfort goals. The 222 is considered to have a very smooth ride.

Trends in Vibration Control Technology

There are two trends in vibration control technology (Fig. 7). First, devices are being refined and improved such that they cost less weight, are more effective, and have better R&M characteristics

(Fig. 8). New devices such as Harmonic Control (HC) are being developed. In the near term it is expected that vibration control devices will be required on new helicopter designs. Second, considerable research is ongoing or planned to control vibration by passive aerodynamics and dynamic tailoring of the rotor and fuselage (Fig. 9). This far-term vibration control approach is expected to reduce dependence on vibration control devices and will pay off in terms of reduced vibration control weight and cost and improved R&M.

Recommended Focus for NASA Vibration Research

NASA should focus on developing the methodology and data base needed to design for inherent low vibration. The key needs are: (1) technology to design rotors for minimal hub forces and moments, and (2) technology to design airframes for minimal dynamic response.

It should be noted that the U.S. Army has a strong program directed at further developing the device approach (see Dr. W. White's presentation). Consequently, NASA need not feel the development of improved vibration control devices is being overlooked.

The above recommendation is in accord with those made by the Aeronautics and Space Engineering Board of the National Research Council in 1978 and the NASA Aeronautics Advisory Committee Rotorcraft Subcommittee in 1979 and 1980.

FIGURE 1. ROTORCRAFT VIBRATION

- DYNAMIC AND AERODYNAMIC COMPLEXITY

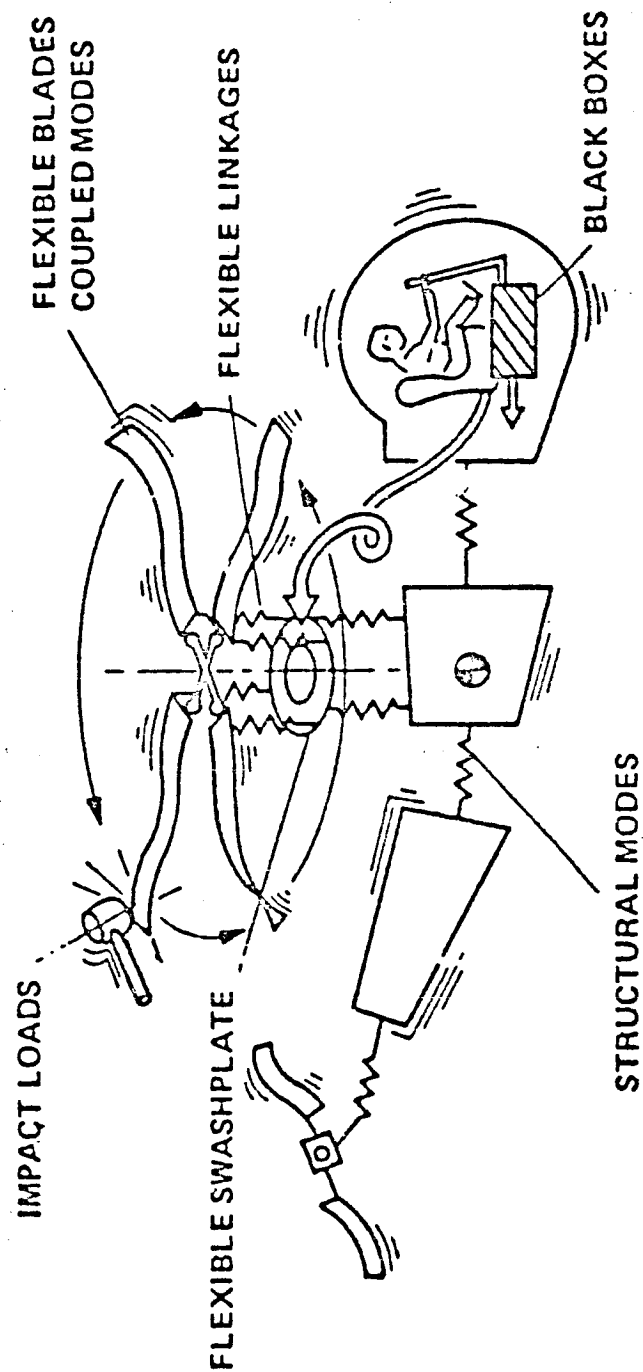


FIGURE 2. OVERVIEW OF VIBRATION CONTROL APPROACHES

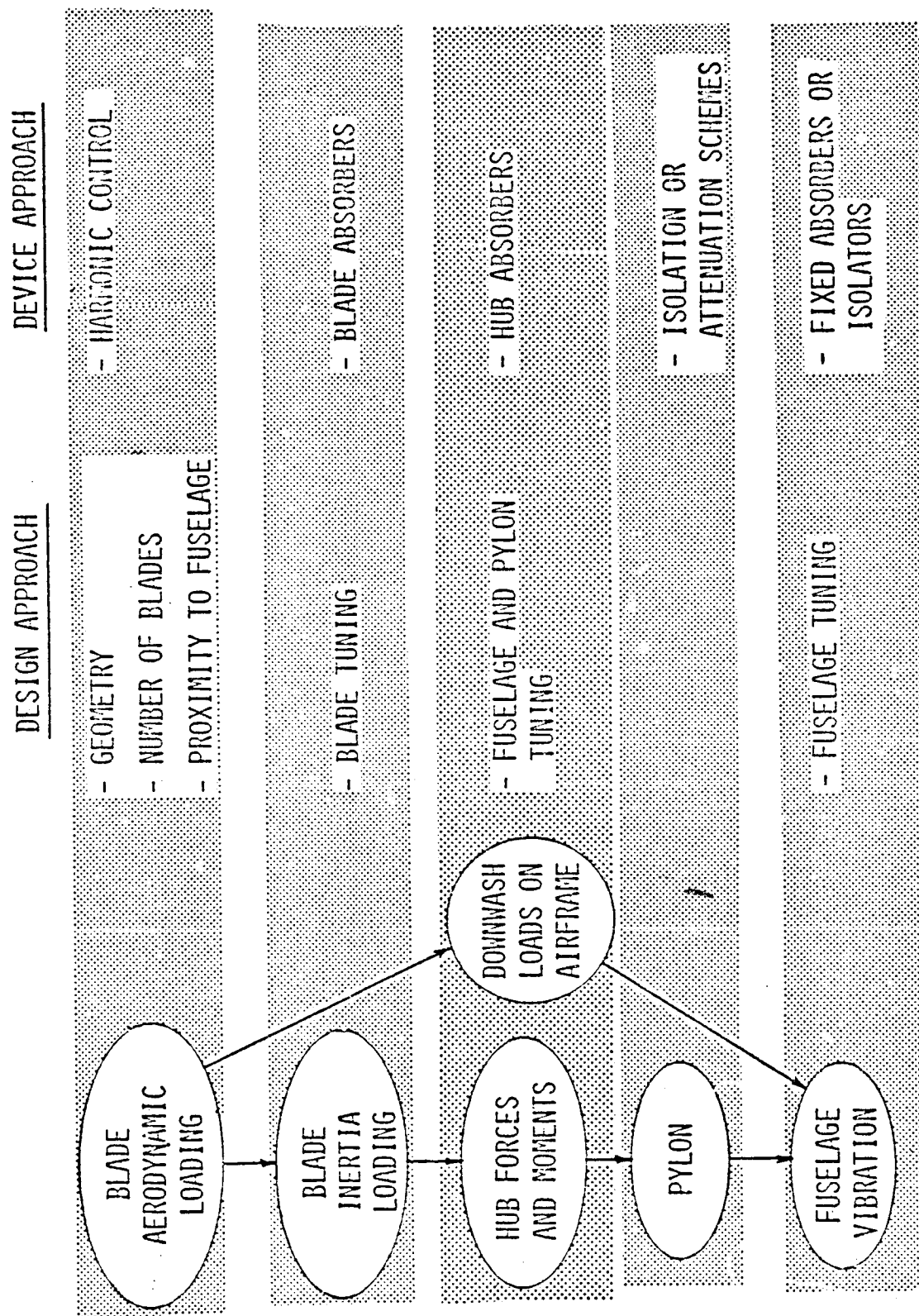


Figure 3. THE STATE OF THE ART OF VIBRATION CONTROL TECHNOLOGY

- METHODOLOGY AND DESIGN TECHNOLOGY IS INADEQUATE TO DESIGN FOR INHERENT LOW VIBRATION
 - INSUFFICIENT DATA AVAILABLE TO PERMIT DESIGNING ROTORS FOR MINIMAL FORCES AND MOMENTS
 - AIRFRAME RESPONSE CANNOT BE ACCURATELY PREDICTED
- HOWEVER DEVICES THAT CAN PROVIDE A SMOOTH RIDE ARE AVAILABLE
 - HUB AND BLADE ABSORBERS
 - PYLON ISOLATION SCHEMES
 - CABIN ABSORBERS/ISOLATORS
 - THE WEIGHT PENALTY IS TYPICALLY 2-3% OF GROSS WEIGHT
 - DEVICES CONTRIBUTE TO OPERATING COST

FIGURE 4. VIBRATION CONTROL DEVICES USED ON SEVERAL MODERN HELICOPTERS

	BELL 222	AEKOSPATIALE AS-350	SIKORSKY S76
ROTATING SYSTEM ABSORBER(S)	✓	✓	✓
PYLON ISOLATION SYSTEM	✓	✓	
FIXED SYSTEM ABSORBER(S)	✓	✓	✓
ESTIMATED WEIGHT PENALTY	2.5%	2.0%	2.4%

FIGURE 5. BELL MODEL 222 VIBRATION CONTROL DEVICES

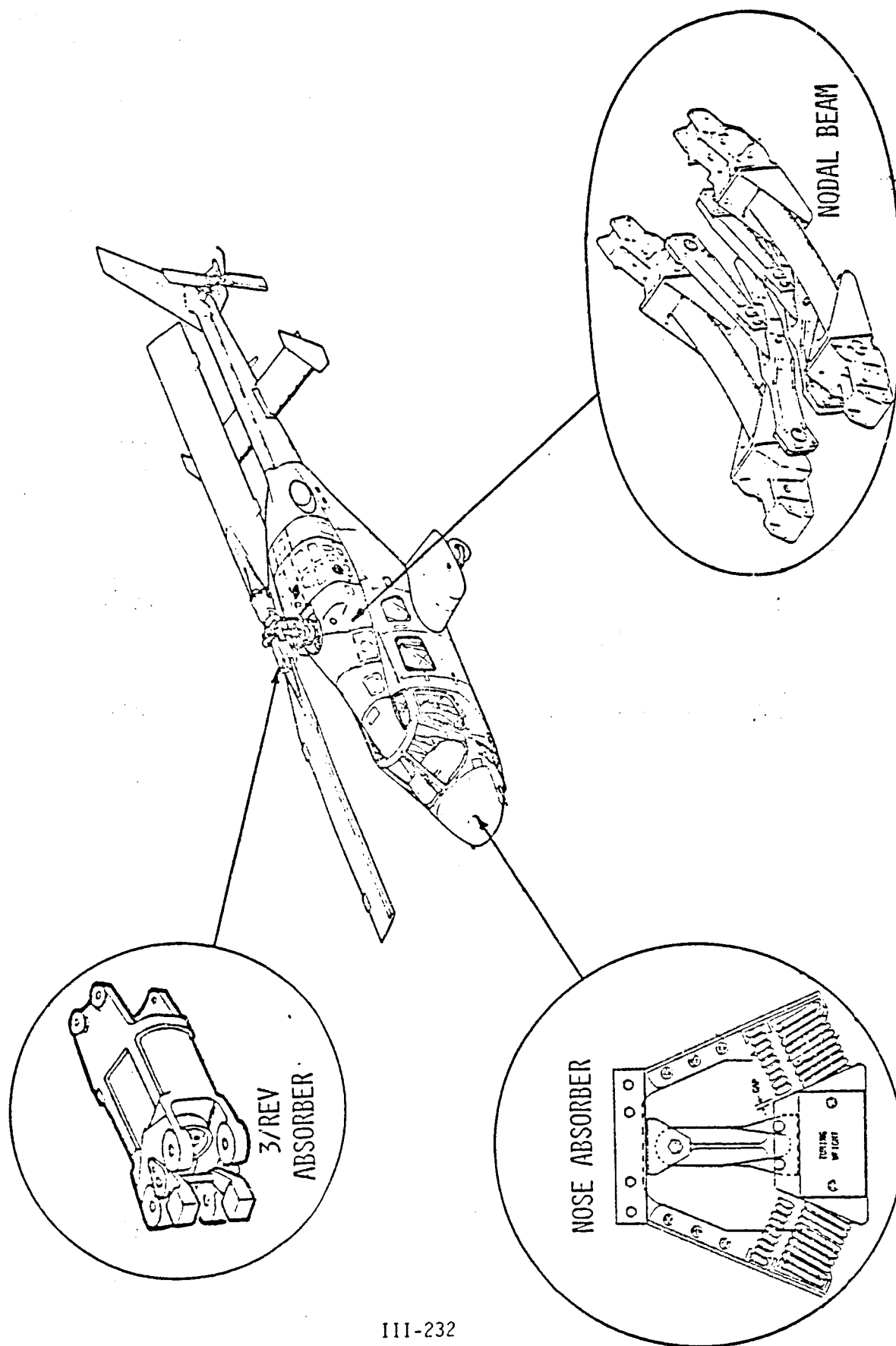


FIGURE 6. MODEL 222 MEASURED 2/REV AND 4/REV VIBRATION

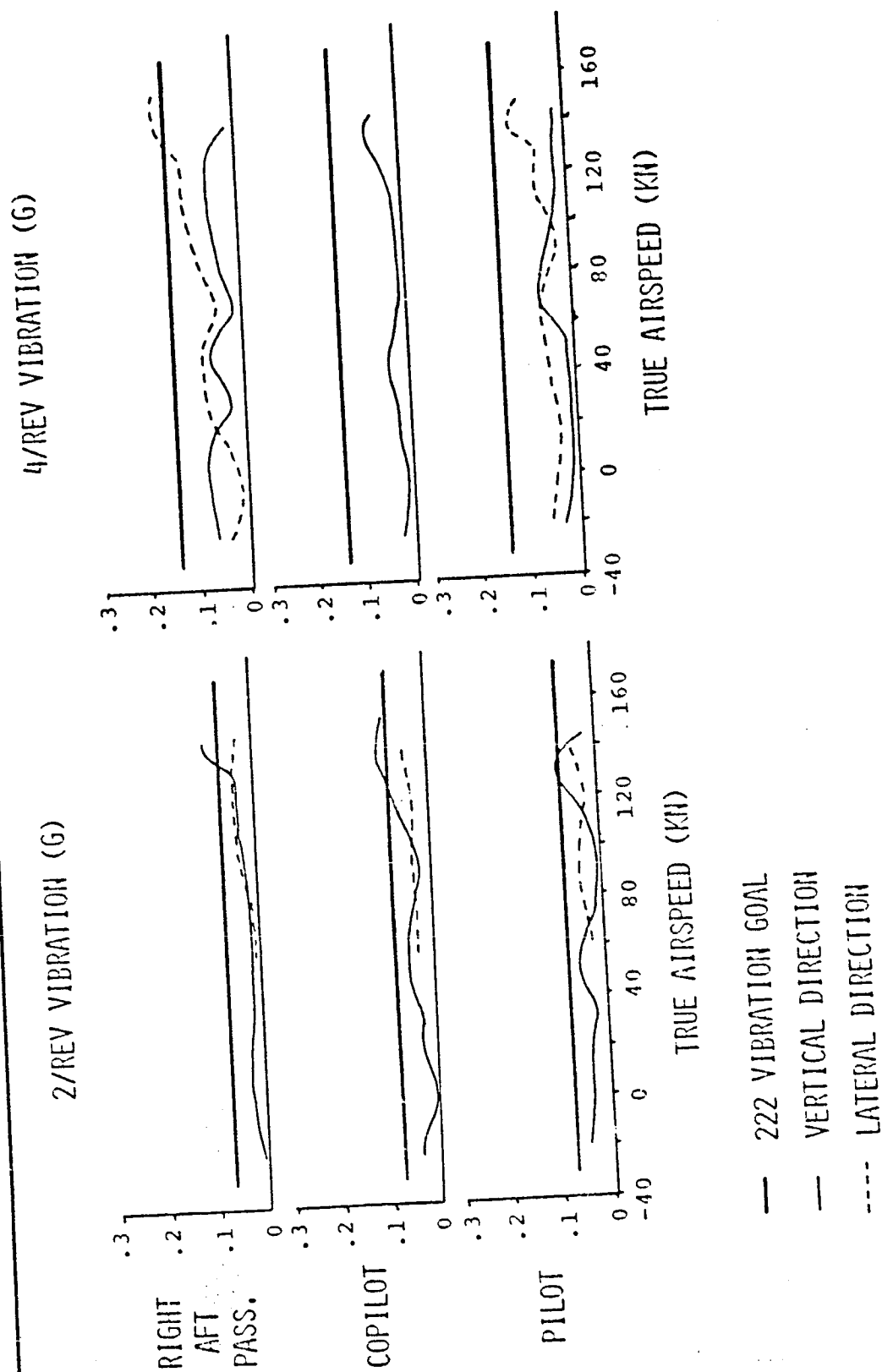


FIGURE 7. TRENDS IN VIBRATION CONTROL TECHNOLOGY

● NEAR TERM

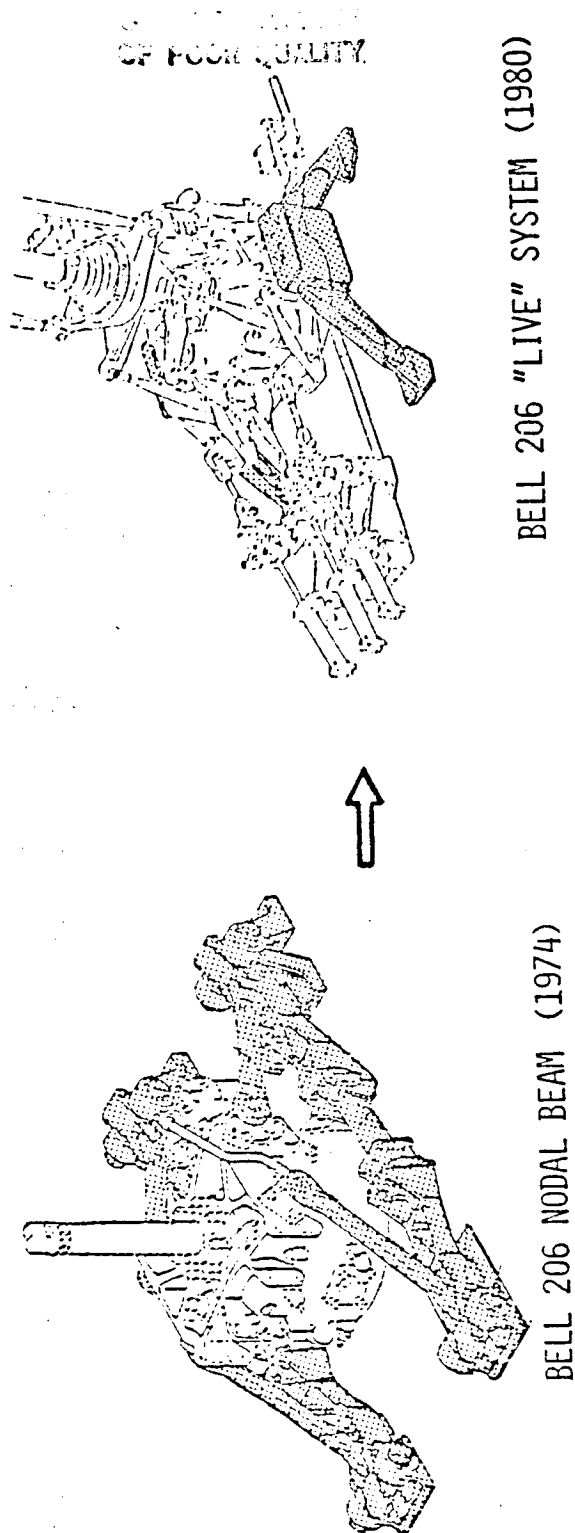
- VIBRATION CONTROL DEVICES WILL CONTINUE TO BE REFINED TO INCREASE EFFECTIVENESS, REDUCE WEIGHT, AND IMPROVE R&M CHARACTERISTICS
- NEW DEVICES WILL BE DEVELOPED

● FAR TERM

- CONTROL OF VIBRATION BY PASSIVE AERODYNAMIC AND DYNAMIC TAILORING OF THE ROTOR, IN CONJUNCTION WITH FUSELAGE TUNING, WILL REDUCE DEPENDENCE ON VIBRATION CONTROL DEVICES
- PAYOFF WILL BE REDUCED WEIGHT AND COST AND IMPROVED R&M

FIGURE 8. EXAMPLE OF REFINEMENT OF VIBRATION CONTROL DEVICES

- NODAL BEAM REFINEMENT



- 50% LESS WEIGHT WITH SAME ISOLATION EFFECTIVENESS
- 50% LESS COST
- IMPROVED R&M CHARACTERISTICS

FIGURE 9. EXAMPLE OF PASSIVE APPROACH POTENTIAL

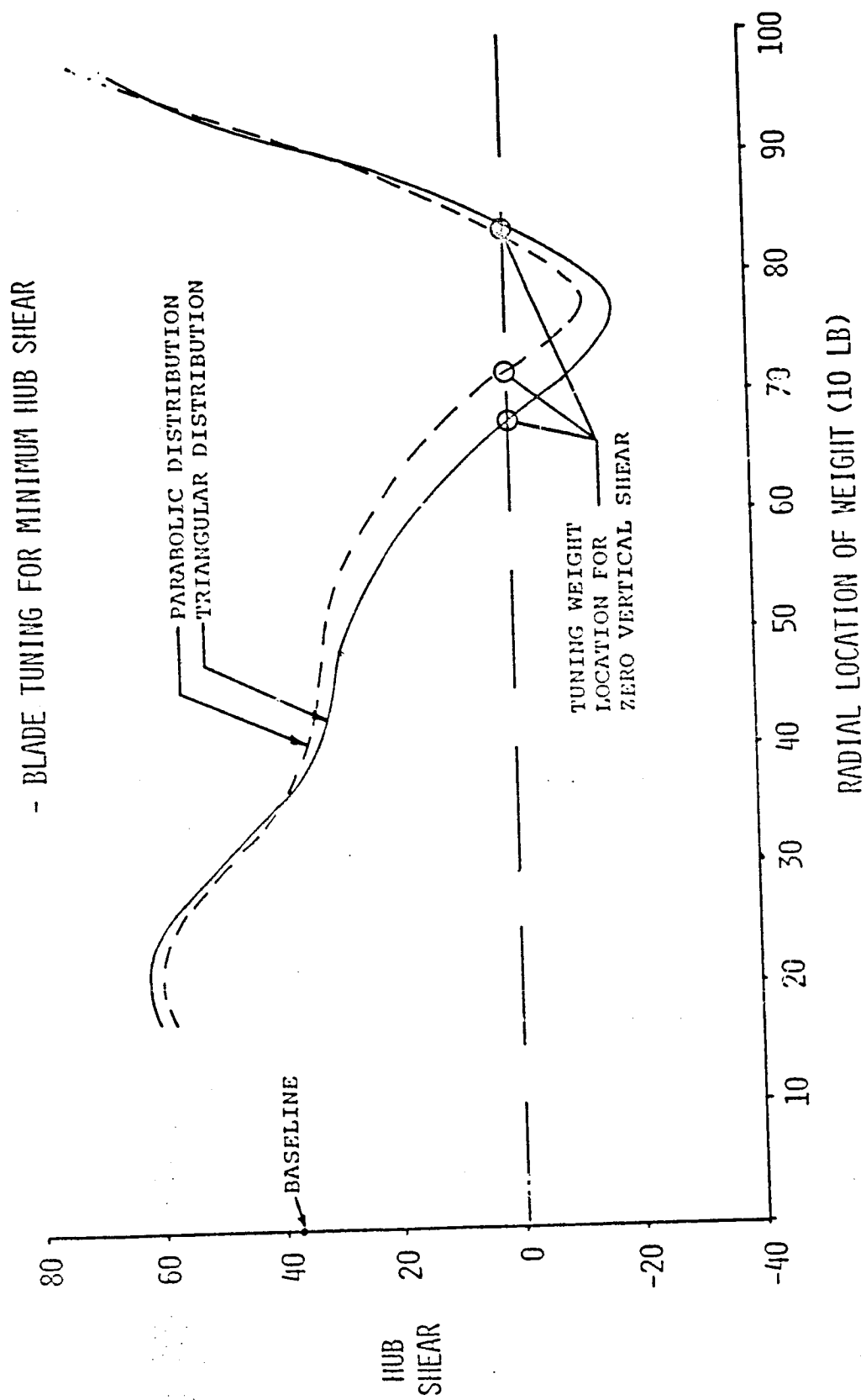


FIGURE 10. RECOMMENDED FOCUS FOR NASA VIBRATION RESEARCH

- CONCENTRATE ON DEVELOPING THE METHODOLOGY AND DATA BASE NEEDED FOR PASSIVE DESIGN APPROACHES
 - AERODYNAMICALLY AND DYNAMICALLY TAILORED ROTORS
 - AIRFRAME DYNAMIC RESPONSE MODELING TECHNIQUES

William F. White Jr
Army Structures Laboratory (AVRADCOM)
ARMY VIBRATION RESEARCH

Historically, helicopter vibrations have been reduced following advances in the basic disciplines of aerodynamics and structural mechanics. Figure (1) illustrates this general trend with early improvements being accomplished primarily by gradual improvements in vibration design approaches. The continuing downward trend over the past two decades has predominantly resulted from the application of numerous vibration control devices. As shown in figure (2), increasingly stringent vibration specifications and acceptance of these devices as a primary solution to the vibration problem have resulted in significant vibration control weight penalties.

Although figure (1) shows significant improvement over the years, current vibration levels are usually achieved by extensive development testing with the attendant increase in system acquisition cost. The severity of the impact of vibration on helicopter acquisition cost is illustrated in figure (3) which shows typical vibration levels of effort during the development cycle of recent procurement programs. During the design phase, there is an increasing level of effort until first flight. At this point, an abrupt increase occurs that extends well into the development cycle and is now extremely costly. Vibration can have a significant impact on overall system productivity. The major areas most often subject to degradation from excessive vibration include: flight envelope limitations, human factors, fatigue life, reliability and maintainability.

Possible solutions to the vibration problem are classified into two complementary categories. These are defined as: (1) vibration design technology which involves selection of design parameters to yield low inherent vibration levels, and (2) vibration control devices which minimize either rotating or fixed system vibratory loads. In practice this division is not possible due to the dependence of vibration control devices on the dynamics of their operating environment. The optimum vibration solution involves selection of those combinations of configuration parameters and control devices that minimizes the impact of vibration on total system productivity.

Vibration design technology involves selection of basic design parameters, subject to other constraints, to yield low inherent vibration levels. This process depends on a fundamental understanding of those combinations of parameters that govern vibratory response. Equally important is the availability of analytical methodology and experimental data bases to guide the selection process. Special and general purpose rotor loads analyses supplemented by data bases are available to select rotor geometric, inertial, and elastic parameters to minimize blade root vibratory loads. Airframe design technology has evolved into the application of large-scale finite element models supported by structural optimization and parameter identification techniques. Rotor/airframe interface design methodology is rapidly improving in the area of analytical modeling of structural interface coupling. Although there has been considerable progress, vibration design technology is inadequate at all levels of the design process. Correlation and comparative studies of rotor and airframe analyses have repeatedly demonstrated the inadequacies of existing design technology. Furthermore, recent Army helicopter development programs illustrate that significant voids exist in design technology that consistently lead to high inherent vibration and extensive development testing.

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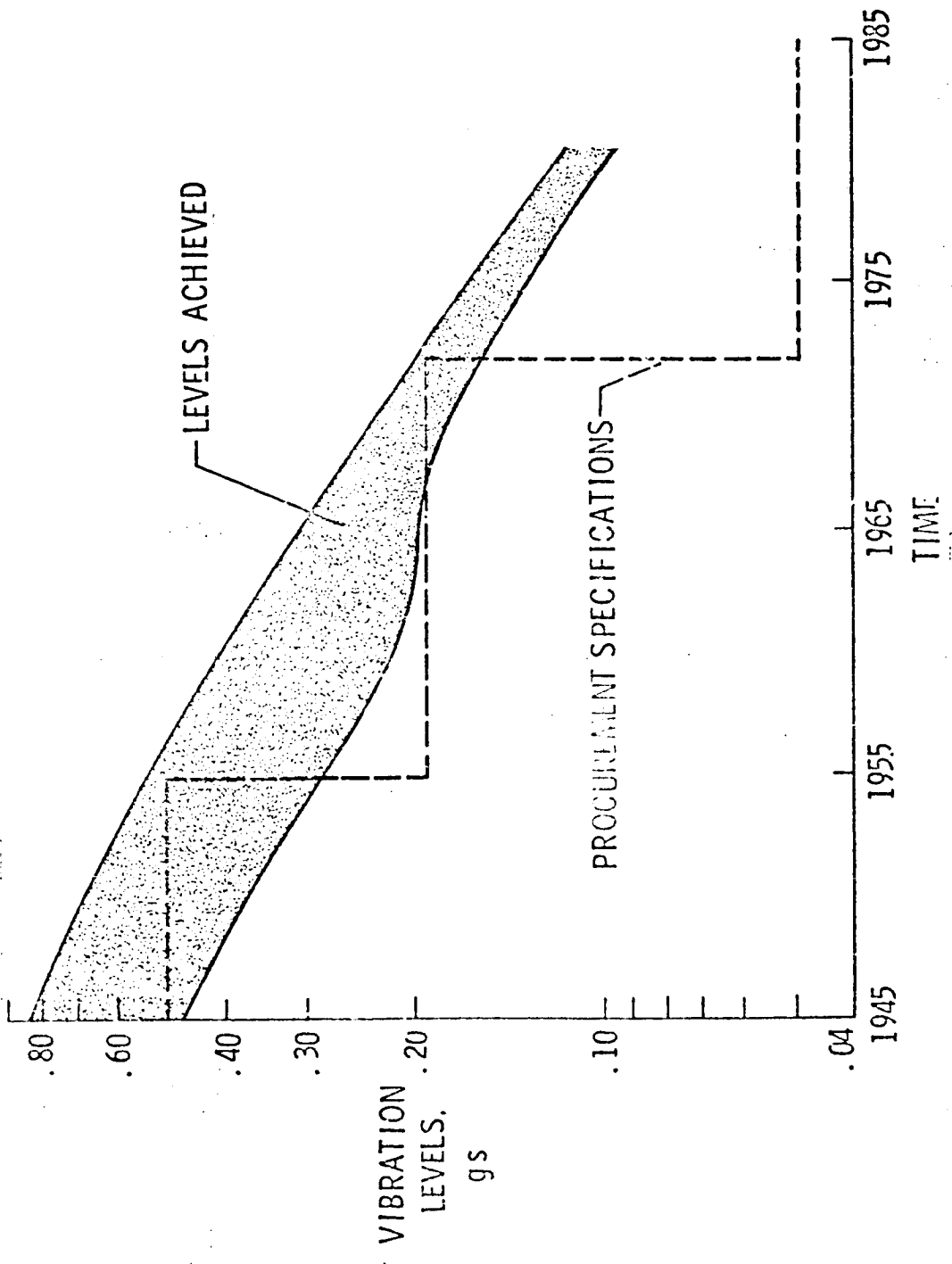
Increasingly stringent Army vibration specifications and voids in design technology have resulted in the development of a wide variety of vibration control devices. In fact, recent trends in helicopter vibration design indicate an acceptance of these devices as the primary solution of the vibration problem. These devices include rotating absorbers, higher harmonic control, fixed-system absorbers, and rotor isolation devices placed between the rotor and airframe interface. Local isolators have been used to isolate seats, instrument panels, cabin floors, fuel tanks, and other vibration sensitive dynamic components. Although the basic principles of most vibration control devices are well understood, the state-of-the-art in vibration control technology is such that successful application often requires extensive trial-and-error testing. A major difficulty with the integration of control devices is the ability to predict their operating environment as characterized by the coupled rotor/control device/airframe system.

Vibration testing involves experimental investigation of structural transfer functions, aerodynamic forcing functions, system response, and empirical standards to evaluate the vibration environment. Vibration testing serves two valuable purposes in helicopter dynamics. First, it provides a basis for understanding the dynamic and vibratory load environment. Second, it supplements voids in existing analytical capability. As conventionally practiced, most helicopter vibration tests provide limited information for resolving vibration issues. Helicopter flight vibration tests provide a direct measure of the actual vibration environment, while full-scale airframe ground vibration tests are most often conducted to correlate analytical predictions of airframe resonances and mode shapes. Typically, vibration problems of the full-scale airframe are extremely difficult to quantify and have been solved during the development cycle by trial-and-error ground and flight vibration testing. Since helicopter vibration problems inherently surface after the test vehicle has been flown, the development of improved ground and flight testing methodology is critical to the vibration solution process.

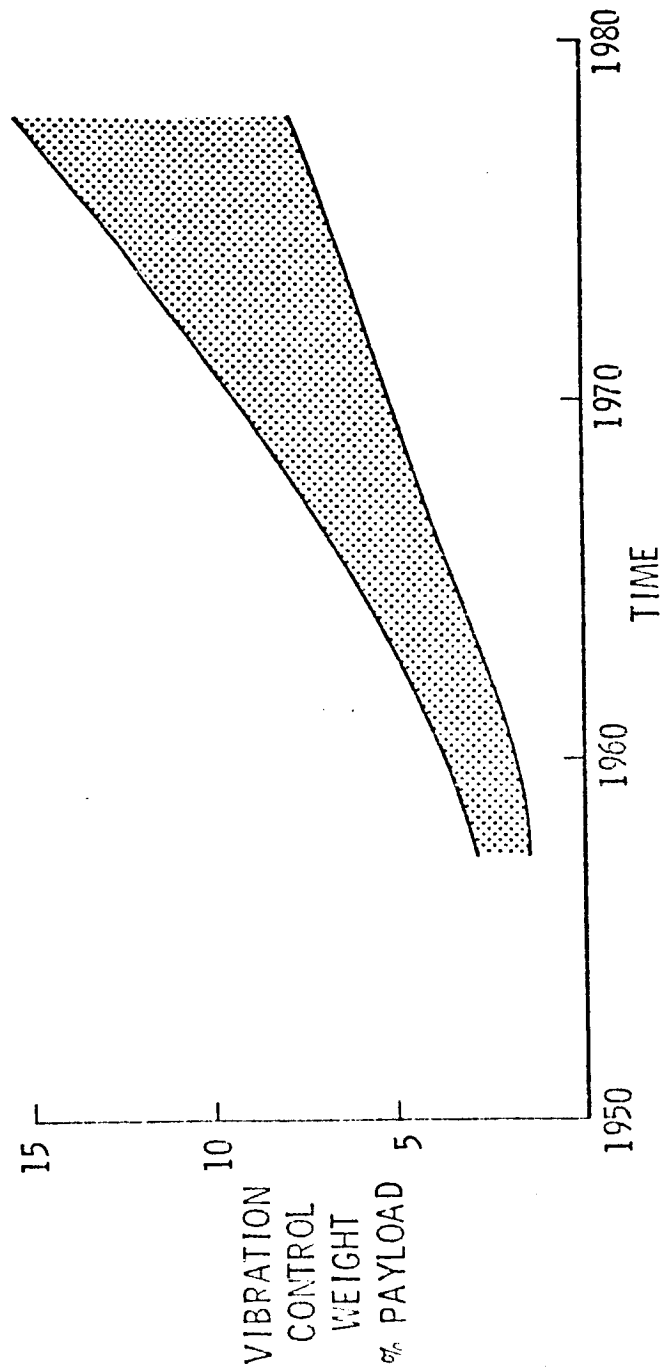
Wind tunnel testing continues to be a fundamental experimental technique to investigate vibratory loads. From the vibration viewpoint, the primary concerns include both rotor shaft and wake-induced vibratory loads. The principal benefits of wind tunnel investigations of vibratory loads include a sorting out of the interplay of variables, improved understanding of the physical mechanisms, and most importantly, identifying what more needs to be known so that adequate vibration design guidelines may be formulated and so that applicable analytical methodology may be developed.

There has been considerable testing to establish human vibration exposure criteria. In many areas it is difficult to extract reliable generalizations from the published literature. In general, the data have been taken under a wide variety of conditions and have been extrapolated to establish subjective human comfort criteria. The extrapolation of existing human factors data introduces two problems. First, there is the possibility of obtaining unnecessarily severe criteria. If vibration specifications are reduced below realistic levels required for military applications, there is a decrease in system productivity due to a rapidly increasing weight penalty. Second, existing data do not provide a rational basis for extrapolation in many areas of concern.

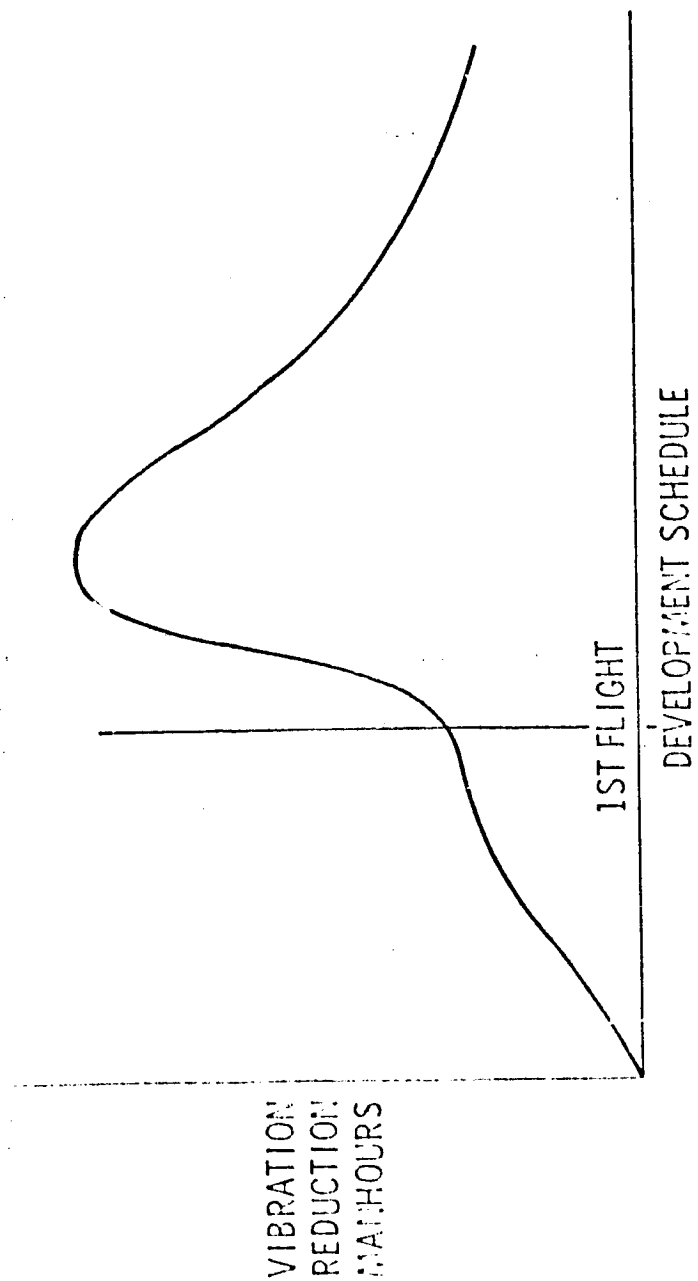
PROGRESS IN HELICOPTER VIBRATION CONTROL



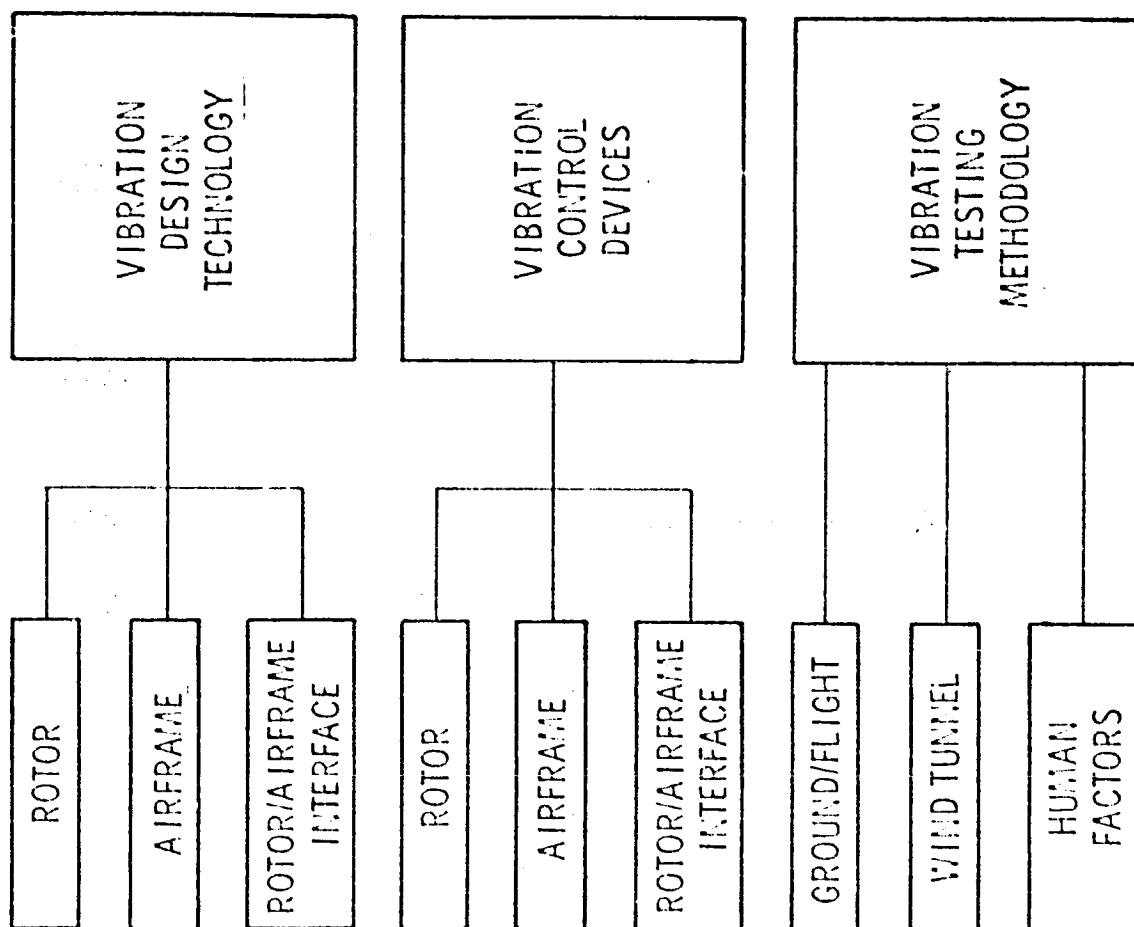
INCREASE IN HELICOPTER VIBRATION CONTROL WEIGHT



IMPACT OF VIBRATIONS ON SYSTEM ACQUISITION



CATEGORIES OF VIBRATION RESEARCH



VIBRATORY LOADS

ASSESSMENT

- THE MAJOR VIBRATION TECHNOLOGY VOID
- CURRENT ANALYSES NOT EFFECTIVE IN THE DESIGN PROCESS
- INSUFFICIENT FEEDBACK BETWEEN VIBRATORY LOADS AND BASIC DISCIPLINES OF AERODYNAMICS AND STRUCTURES
- DEFICIENCIES HAVE LED TO OVER RELIANCE ON VIBRATION CONTROL DEVICES

AIRFRAME STRUCTURAL DYNAMICS

ASSESSMENT:

- A SIGNIFICANT VIBRATION TECHNOLOGY VOID
- EXISTING METHODOLOGY NOT COMPLETELY RESPONSIVE IN THE DESIGN PROCESS
- NASTRAN CONTAINS MOST OF DESIRED CAPABILITY
- PROBLEM IS INCOMPLETE UNDERSTANDING OF MODELING REQUIREMENTS FOR HELICOPTERS

ROTOR/AIRFRAME INTERFACE

ASSESSMENT:

- SIGNIFICANT VIBRATION TECHNOLOGY VOID
- COUPLED RESPONSE HIGHLY DEPENDENT ON
 - STRUCTURAL DYNAMIC COUPLING
 - INTERACTIONAL AERODYNAMIC COUPLING
- WIDE BASE OF RESEARCH ON STRUCTURAL ASPECTS
- INADEQUATE EMPHASIS ON AERODYNAMIC COUPLING

VIBRATION CONTROL DEVICES

ASSESSMENT:

- SUBSTANTIAL LEVEL OF EFFORT WITHIN RTL
- GOOD BALANCE BETWEEN ACTIVE CONTROLS, ISOLATOR, AND ABSORBER CONCEPTS
- CONTINUED EMPHASIS IS CRITICAL TO VIBRATION SOLUTION PROCESS

VIBRATION TESTING

ASSESSMENT:

- GROUND AND FLIGHT VIBRATION TESTING IS A MAJOR VIBRATION EFFORT WITHIN RTL
- INSUFFICIENT USE OF WIND TUNNELS FOR EXPERIMENTAL INVESTIGATIONS OF A FUNDAMENTAL NATURE
- HUMAN FACTORS VIBRATION DATA BASE INSUFFICIENT TO DEVELOP COMPREHENSIVE CRITERIA

CONCLUSIONS

AREAS OF STRONG EMPHASIS

- VIBRATION CONTROL DEVICES
- ROTOR/AIRFRAME STRUCTURAL DYNAMIC COUPLING
- GROUND AND FLIGHT TESTING

MAJOR VIBRATION VOIDS:

- ROTOR LOADS METHODOLOGY
- AERODYNAMIC INTERACTION VIBRATION SOURCES
- WIND TUNNEL INVESTIGATIONS OF FUNDAMENTAL NATURE

SIGNIFICANT VIBRATION VOIDS

- AIRFRAME STRUCTURAL DYNAMICS
- ROTOR/AIRFRAME INTERFACE
- HUMAN FACTORS VIBRATION DATA BASE

E. R. Wood
Hughes Helicopters Inc.
COMMENTS ON VIBRATION REDUCTION
FOR HAA/NASA ADVANCED TECHNOLOGY WORK SHOP

NASA's recent emphasis on improved modelling for helicopter fuselage dynamics is to be commended. Especially noteworthy is the recent Boeing-Vertol contract for an improved dynamic NASTRAN finite element model. This program is being funded by the NASA-Langley Research Center. We are pleased by the structure of the program in that it permits all of the helicopter companies to participate. Also, we are pleased that in this activity emphasis has been placed on having a company use the same structural model for dynamic NASTRAN as used by the structures' people for static loads and stresses. It is not only costly to maintain two separate NASTRAN structural models, but also difficult to keep each both equally well updated.

While good mathematical models are important, we should be careful not to overemphasize the role of finite element models in helicopter dynamics. Once the aircraft is built and vibration tests complete, we have the opportunity to take advantage of analyses based upon use of actual aircraft dynamic test data. We have found experimental vibration data to be invaluable in analyses to explore such areas as: (1) frequency changes due to changes in stiffness and mass distribution; (2) mobility studies to determine the optimum location for fixed tuned vibration absorbers; and (3) establishing dynamic forced response of the fuselage by modal superposition.

Another area where we would encourage NASA support is in research to explore the relative contribution to fuselage vibration due to main rotor and horizontal tail surface excitation respectively. For example, most dynamicists agree that the relatively high vibration levels experienced in helicopters in the 30 to 40 knot regime are primarily due to main rotor excitation resulting

from blade-vortex interaction. Not as well understood, however, is the source of high speed vibration. Inflight investigations at Hughes Helicopters have shown that significant excitation at high speed arises from the main rotor wake impinging on the horizontal stabilizer. For example, we recently flew one of our helicopters to 100 knots with and without a horizontal tail surface. The data showed vibration levels at 100 knots without the tail surface to be about one-third those measured with the tail surface installed. This area is open for further investigation by NASA researchers.

My comments would not be complete without some mention of Higher Harmonic Control. This subject evoked considerable interest at the AHS Forum last May, and already some discussion at this meeting. We at Hughes are fortunate to be tasked with the NASA/Army project to flight test a higher harmonic control system on an OH-6A in August 1981. I believe that both Government and industry are watching this effort to see whether HHC offers the promise to reduce helicopter vibration levels by such an amount as to bring us closer to our long-sought dream of a jet-smooth ride. As most of you are aware, the first efforts in this area were done by Jan Drees of Bell in 1963 on an UH-1A using mechanical means. Today with the promise of advanced miniturized electronics, it appears that we have a better opportunity of meeting that goal. Should HHC prove feasible, there is little question in my mind that the rest of our industry would move quickly to incorporate such a concept in their helicopters. We feel we have a sobering responsibility to all of you in making sure that our forthcoming HHC flight test program provides an objective and honest evaluation.

D. S. Jenney - Sikorsky

Key Points:

1. Government and industry must develop and correlate a predictive capability so vibrations can be reliably treated at the design stage.
2. Vibrations should be reduced at the source. Better reliability of hardware will be the primary benefit now that passenger levels are low.
3. New vibration concepts such as HHC need test and evaluation - of sufficient scope to be sure the proper conclusions on their viability are reached.
4. Operational problems of track and balance and vibration trouble-shooting deserve some fundamental research.

USER-ORIENTED VIBRATION PROBLEMS

1. WEIGHT, COST AND R&M OF VIBRATION CONTROL DEVICES.
 - REQUIRES CONTINUED DEVELOPMENT OF MORE COST-EFFECTIVE APPROACHES.
2. MAINTENANCE COSTS CAUSED BY VIBRATION-INDUCED FAILURES.
 - REQUIRES CLOSER ATTENTION TO VIBRATION IN EQUIPMENT AREAS.
3. TRACK AND BALANCE (NON NP VIBRATION).
 - REQUIRES COST EFFECTIVE CONTROL OF CRITICAL TOLERANCES.
4. DIAGNOSING AND CORRECTING UNUSUAL VIBRATION.
 - REQUIRES STATISTICAL DATA AND AUTO SENSING EQUIPMENT.
5. CREW AND PASSENGER COMFORT.
 - REQUIRES CONTINUED DEVELOPMENT OF MORE COST-EFFECTIVE APPROACHES.

1. CONDUCT STUDY TO DETERMINE IMPACT OF VIBRATION ON USER COSTS AND PRIORITIZE COST ELEMENTS.
2. DEMONSTRATE FEASIBILITY OF USING (WITH HIGH CONFIDENCE) VIBRATION SIGNATURES FOR MONITORING STATE OF AIRCRAFT.
3. DEVELOP A MINIMUM COST APPROACH FOR TRACK AND BALANCE CONTROL.
4. DEVELOP TECHNIQUES FOR IMPROVING VIBRATION PREDICTIVE CAPABILITY.
 - EXCITATION, RESPONSE
5. DEVELOP TECHNIQUES FOR RAPIDLY OPTIMIZING VIBRATION DURING DEVELOPMENT.
 - SHAKE TEST, FORCE IDENTIFICATION, SYSTEM IDENTIFICATION, OPTIMIZATION
6. SPONSOR DETAIL DESIGN STUDIES OF VIBRATION CONTROL CONCEPTS.
 - ACTIVE, PASSIVE, ISOLATION CONCEPTS

Vibrations Session - Discussion

- . NASA's NASTRAN correlation efforts using the CH-47 are an updated repeat of earlier attempts to correlate with the CH-53. Opinions on the likelihood of success varied widely. There have been many failures at attempts to use NASTRAN for dynamics predictions - probably related to inability to adequately describe the structure, not to any errors of the program itself.
- . When hardware is available, modal models based on shake test can be more accurate, useful math models, than a finite-element model.
- . NASA was urged to develop some generalized vibration test facility. Earlier guidance to NASA has pointed away from configuration-specific solutions, so the facility would have to be generic. Perhaps NASA would better fund individual organizations to build their (several) specific capabilities. That is the approach now being taken.
- . What is the follow-on to higher harmonic control tests on the OH-6? No further funds allocated. Results to be correlated and technology available to new production - perhaps AH-64 or UH-60. If results are poor or marginal, more resources should be applied to be sure we get a proper evaluation.
- . Should NASA support rotor hub concept development? Responses varied from "no" to "yes, as part of total rotor improvement."

Composites Panel

Chairman and Keynote	- John Shipley, U.S. Army, Langley
NASA Representative	- H. Bensen Dexter, Langley
William Peck	- Boeing Vertol
Paul Tanimoto	- FAA
John Pim	- LTV

Discussion

COMPOSITE APPLICATIONS FOR HELICOPTERS

HAA/NASA Advanced Rotorcraft Technology Workshop

John L. Shipley

Structures Laboratory

US Army Research & Technology Laboratories (AVRADCOM)

Almost from the beginning of the first successful helicopter, there have been sporadic attempts to incorporate composites of some form into helicopters. In 1943 Sikorsky had plastic impregnated wood cowlings on the R-5A and streamlining with molded plastic impregnated fiberglass cloth on the R-6A. As early as 1950, an all fiberglass and plastic laminated skin weighing 35 pounds was successfully tested and flown on the YH-32. The first all composite primary structure was the fiberglass rotor blade built for the Kaman HH-43B and flown in 1962 but did not enter production because the one-for-one metal replacement made production costs prohibitive. As fabrication costs for metals increased and composite raw material costs decreased, the efforts to apply composites to helicopters became more systematic, and in 1970 fiberglass blades were flown on the CH-47, and boron blades were flown on the same helicopter the following year. In 1973 composite flight controls were demonstrated and a durability evaluation of composites was initiated with the flight service program of the boron reinforced tail cone on the CH-54. Current state-of-the-art in helicopter composites can be assessed by the significant events which have happened in this area for the past few years with military related aircraft in the United States. In 1974 the Army's Blackhawk was first flown with a graphite tail rotor, titanium and composite rotor blades, boron stiffeners, and 20% of the exterior surface of Kevlar and fiberglass. That same year all composite HH rotor blades were also tested. In 1975 the Advanced Attack Helicopter was flown with metal and fiberglass multiple spar blades and 25% of the exterior surface made from Kevlar and glass. During the same year composite manufacturing flexibility provided improved survivability with an all composite multiple tubular spar concept, and an all composite drive shaft was demonstrated. In 1976 the feasibility of filament winding of large components was demonstrated with a tail cone on the AH-1, as was the effectiveness of all bonded structures on the HH fuselage components. As a part of the Army's product improvement program for the AH-1, all composite main rotor blades were flown in 1977. That same year the feasibility of all composite hubs were demonstrated with a 1/2 scale CH-54 system, and composite landing gears were tested for the AH-1. As part of another Army product improvement program, all composite blades for the CH-47D and the bearingless main rotor entered flight test in 1978.

This systematic and dedicated effort to introduce the widespread applications of composites in helicopters has been brought about because of their potential impact in three key areas of interest to the Army. In the area of performance, composites offer reduced empty weight, manufacturing flexibility for aerodynamic shaping, and tailoring of dynamic response. To survivability, composites offer improved ballistic and bombing damage tolerance, improved fatigue and fracture mechanics, and in some cases,

reduced detectability. Acquisition and operational costs of helicopters can be reduced by composites through reduction in manufacturing manhours, raw material requirements, parts counts, and maintenance manhours per flight hour. In addition, composites should improve field repairability, availability and utilization life. Studies have shown that these advantages of composites are applicable to over 58% of the helicopters empty weight, and that organic matrix composites are ideally suited for about 95% of these applications with metal matrix composites best suited with the remaining 5% of these applications.

Component and systems studies and development programs have substantiated these potential benefits of composites. For main rotor blades, composites offer a 10% weight and cost reduction in addition to aeroelastic tailoring, ballistic tolerance and improved producibility. In the area of the hub, composites provide the capability for failsafe designs as well as a 25% weight reduction and 50% cost reduction. Application of composites to tail rotors will result in reduced maintenance, 25% cost reduction, and a 10% weight reduction. These investigations and development programs have shown that all composite landing gears can result in improved crashworthiness, 25% cost reduction, and a 10% weight reduction. Development programs in airframe components have led to the conclusion that weight and cost reductions on the order of 20% can be achieved through the application of composites to helicopter fuselages. These investigations gave impetus to the Army's pre-design studies and subsequent RFP for the Advanced Composite Airframe Program. In addition to providing for current day specifications with regard to ballistic tolerance, crashworthiness, reliability, and maintainability, a major program goal is to demonstrate a 22% airframe weight savings and a 17% reduction in airframe acquisition costs. In addition to demonstration of the improvements in airframe performance and capability through the use of advanced materials, the ACAP Program's objective is to establish confidence in composites within the helicopter industry and the potential users.

The Army's ACAP Program and development demonstration programs at the component level represent a 1980 technology potential of composites. Within this technology, the factors which affect or restrict the full realization of composite potential continues to be the required demonstration to the user, producer, and certifier prior to advocacy on a major system; high cost of research and development prohibits the historical cut-and-try techniques; conservative fatigue and durability design allowables are based on limited knowledge and in some cases, prevailing rumors; the analytical and design techniques available in the laboratory are not reflected in the production design techniques; one-for-one composite replacements for the metal counterpart is still prohibitive; the energy absorption and impact damage tolerance of composites has to be increased to that of metals either through material changes or design concepts; and structural optimization through the application of composites for static strength and dynamic tuning has to be validated. These factors represent the areas of emphasis for the next generation composite technology for helicopters.

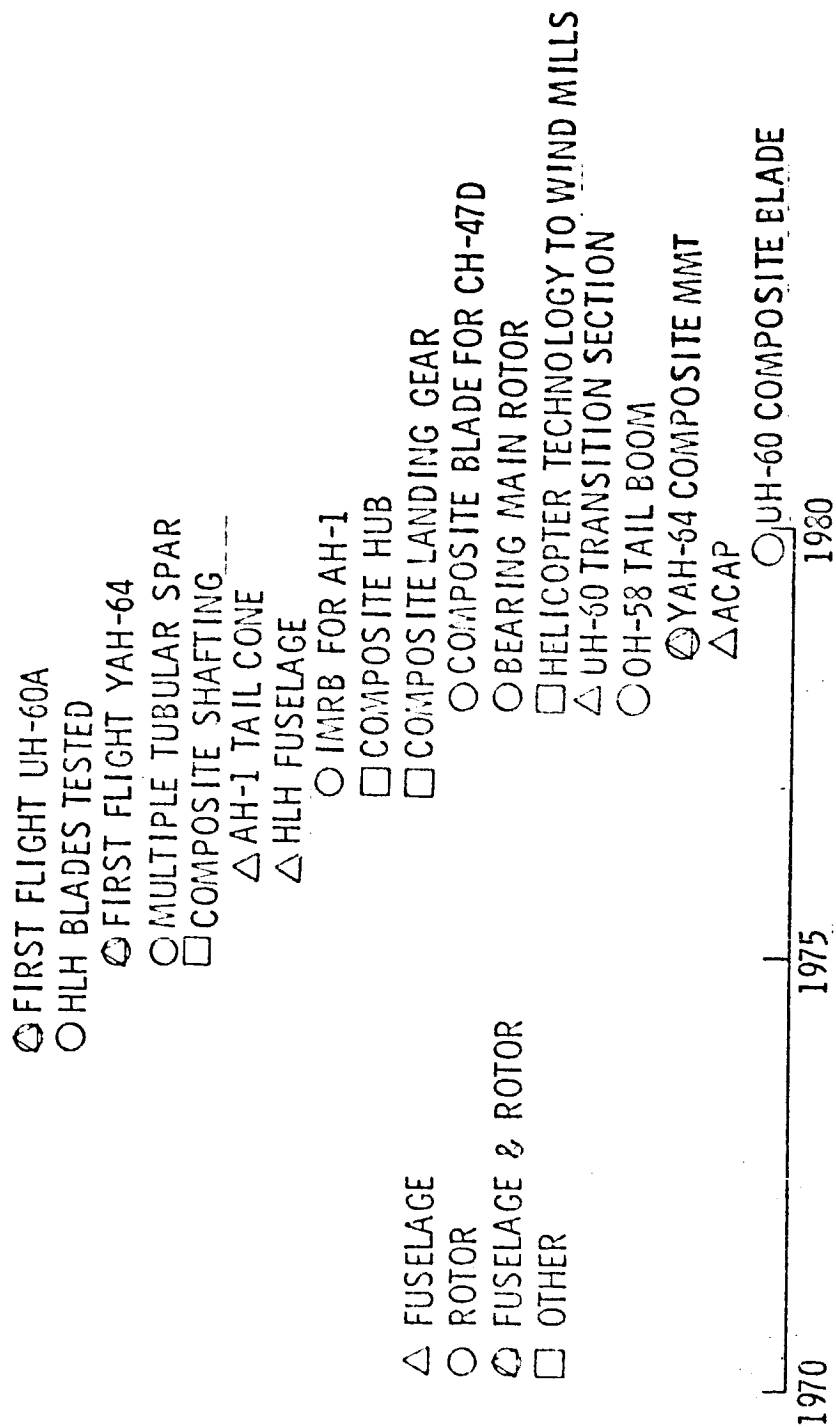
COMPOSITES TECHNOLOGY

- HISTORY OF COMPOSITE APPLICATIONS TO HELICOPTERS
- WHY COMPOSITES
- CURRENT TECHNOLOGY
- FUTURE RESEARCH REQUIREMENTS

######

HELICOPTER STRUCTURES AND MATERIALS

CURRENT TECHNOLOGY



POTENTIAL IMPACT OF COMPOSITES IN HELICOPTERS

- PERFORMANCE
 - REDUCED EMPTY WEIGHT
 - MANUFACTURING FLEXIBILITY FOR AERODYNAMIC SHAPING
 - TAILORING OF DYNAMIC RESPONSE
- SURVIVABILITY
 - BALLISTIC AND HANDLING DAMAGE TOLERANCE
 - IMPROVED FATIGUE AND FRACTURE MECHANICS
 - REDUCED DETECTABILITY
- COST
 - REDUCED MANUFACTURING MANHOURS
 - REDUCED RAW MATERIALS REQUIREMENT
 - REDUCED PARTS COUNT
 - REDUCED MAINTENANCE MANHOUR PER FLIGHT HOUR
 - IMPROVED FIELD REPAIRABILITY
 - INCREASED AVAILABILITY
 - INCREASED UTILIZATION LIFE

POTENTIAL ADVANTAGES OF COMPOSITE ROTOR BLADES

ELIMINATES CORROSION
IMPROVES FATIGUE LIFE
SLOW DETECTABLE FAILURE PROPAGATION
AUTOMATED MANUFACTURING TECHNIQUES
IMPROVED QUALITY CONTROL
DAMAGE RESISTANT
REPAIRABLE
DYNAMIC TAILORING
SHAPE AND CONTOUR FREEDOM

FUNCTIONAL APPLICATION OF COMPOSITES TO HELICOPTERS

<u>WEIGHT STATEMENT GROUP</u>	<u>% EMPTY WEIGHT</u>	<u>COMPOSITE APPLICATIONS</u>	
		<u>ORGANIC</u>	<u>METAL MATRIX</u>
MAIN ROTOR GROUP	15.8		
BLADES	(7.0)	X	
HUB	(7.5)	X	
ISOLATOR	(1.3)		
TAIL GROUP (ROTOR AND FINS)	3.5	X	
BODY GROUP	17.5	X	
LANDING GEAR GROUP	6.4	X	
ENGINE SECTION GROUP	1.8	X	X ⁽¹⁾
PROPULSION GROUP	25.6		
ENGINES (EXH. CON. START)	(8.2)		
FUEL SYSTEM	(3.2)	X	
DRIVE SYSTEM	(14.3)		
GEAR BOX (CASING/HOUSING)	(2.9)		X ⁽¹⁾
SHAFTING (ENGINE TO TRANS, ETC)	(0.4)	X	X
ACCESS DRIVE	(0.3)	X	X
SHAFTS	(0.8)	X	
ROTOR SHAFT	(1.3)	X	X
OTHER (SEALS, GEARS, LUBE SYS, ETC)	(8.6)		
FLIGHT CONTROL SYSTEM	6.7		
COCKPIT	(0.9)		
SYSTEM	(5.5)	X	
SAS AND FAS	(0.3)		
OTHER (AUX POWER, INST, HYD, PNEU, ELEC, AVIONICS, ARM, FURNISH, A/C, ANTI ICING, ETC)	22.6		

(1) SELECTIVE REINFORCEMENT FOR STIFFNESS AND STRENGTH

APPLICATION OF COMPOSITES TO HELICOPTER STRUCTURES

- COMPOSITES OFFER POTENTIAL ADVANTAGE TO 58% OF HELICOPTER
EMPTY WEIGHT
- ORGANIC MATRIX COMPOSITES IDEALLY SUITED FOR 89% OF THESE
APPLICATIONS
- METAL MATRIX COMPOSITES IDEALLY SUITED FOR 5% OF THESE
APPLICATIONS
- BOTH MATRIX COMPOSITES OFFER SOME ADVANTAGES FOR 6% OF
THESE APPLICATIONS

STRUCTURES AND MATERIALS RESEARCH AND DEVELOPMENT

SCOPE

- FATIGUE AND FRACTURE MECHANICS
- STRUCTURAL ANALYSIS TECHNIQUES
- STRUCTURAL DESIGN CRITERIA
- BALLISTIC DAMAGE TOLERANCE
- ENERGY ABSORPTION CAPABILITIES
- DURABILITY AND ENVIRONMENTAL EFFECTS
- MANUFACTURING TECHNIQUES
- APPLICATION OF ADVANCED MATERIALS

L-19-0117

FATIGUE / 100 W/STRENGTH / 100 W/STRENGTH

CHARTER / 100 W/STRENGTH / 100 W/STRENGTH

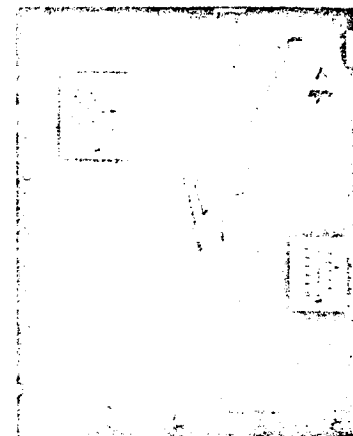
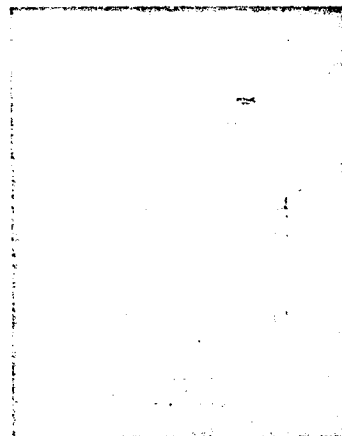
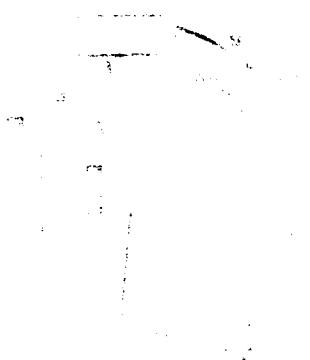
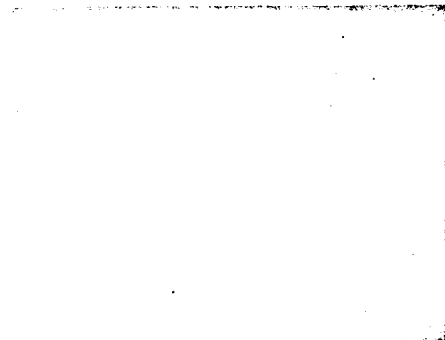
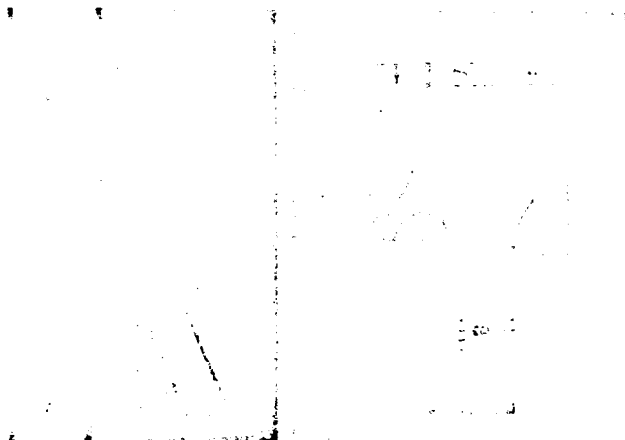
HELICOPTER / 100 W/STRENGTH / 100 W/STRENGTH

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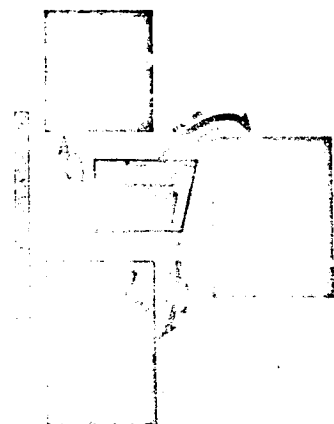
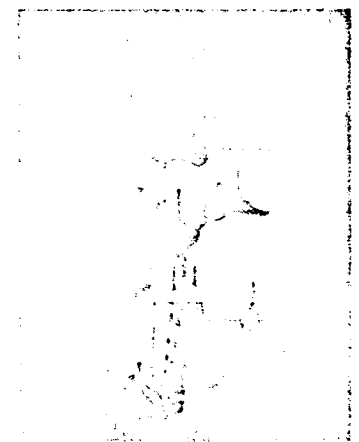
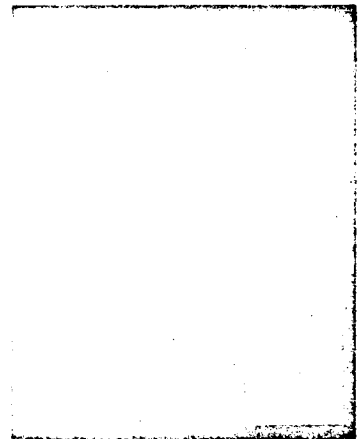
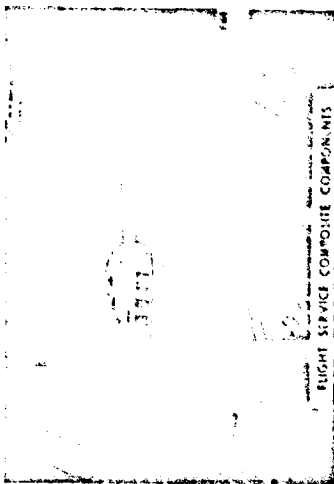
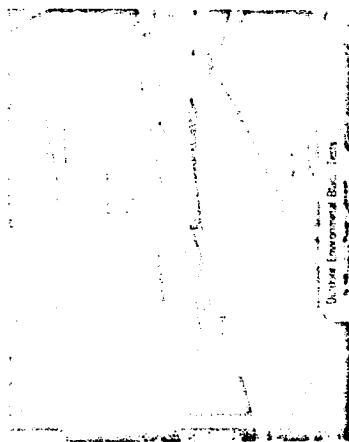
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TOWARDS TOUGHER COMPOSITES
 THE PARTIAL INTERLAMINAR SEPARATION SYSTEM

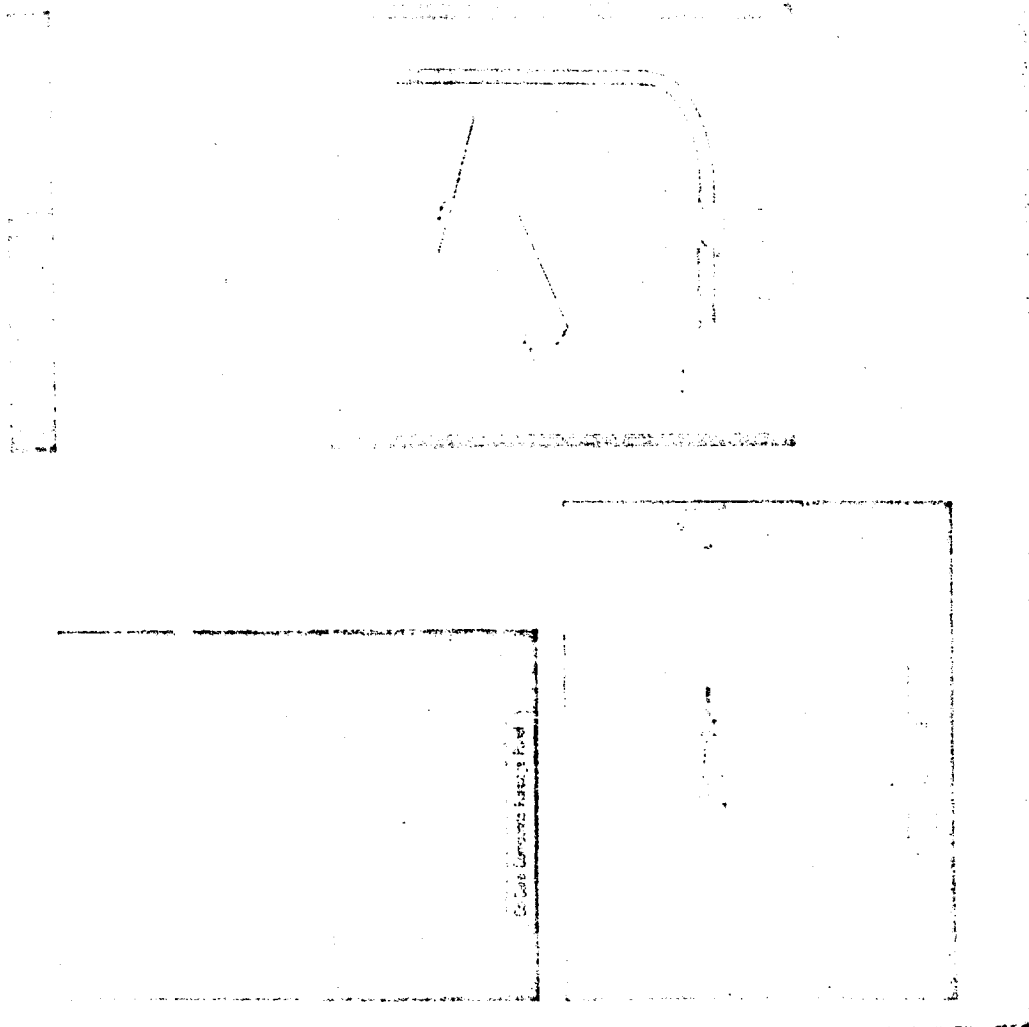
PARTIAL INTERLAMINAR SEPARATION SYSTEM
 PARTIAL INTERLAMINAR SEPARATION SYSTEM

ORIGINAL PAGE
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DIRECTORY



ORIGINAL PAGE
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POTENTIAL AIRCRAFT

11

Main Rotor Blades

Fuselage Components

Landing Gear

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• 100% Cotton
• 100% Polyester
• 100% Nylon
• 100% Rayon
• 100% Silk
• 100% Wool

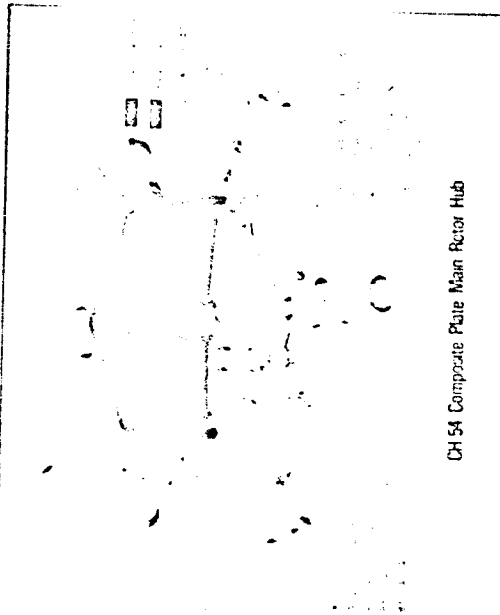
U.S. Composite Series Book End

U.S. Composite Series Book End

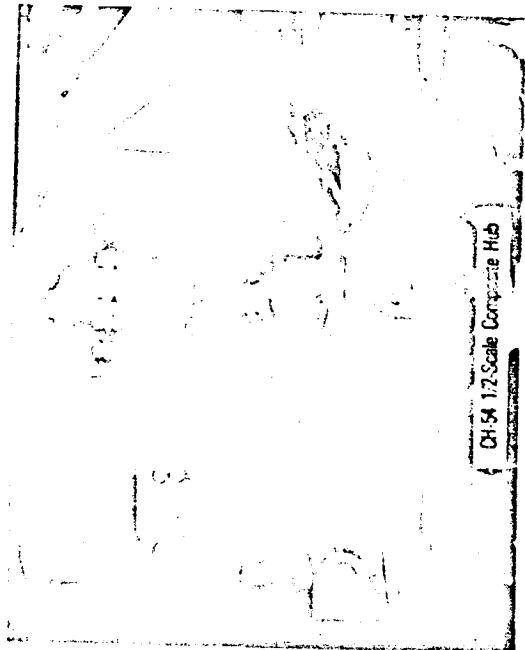
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POTENTIAL IMPACT
 • 25% WEIGHT REDUCTION
 • 50% COST REDUCTION
 • FAIL SAFETY
 • LOW RCS

USCGA Composite Hub PO



CH 54 Composite Plate Main Reactor Hub



CH 54 1/2 Scale Composite Hub

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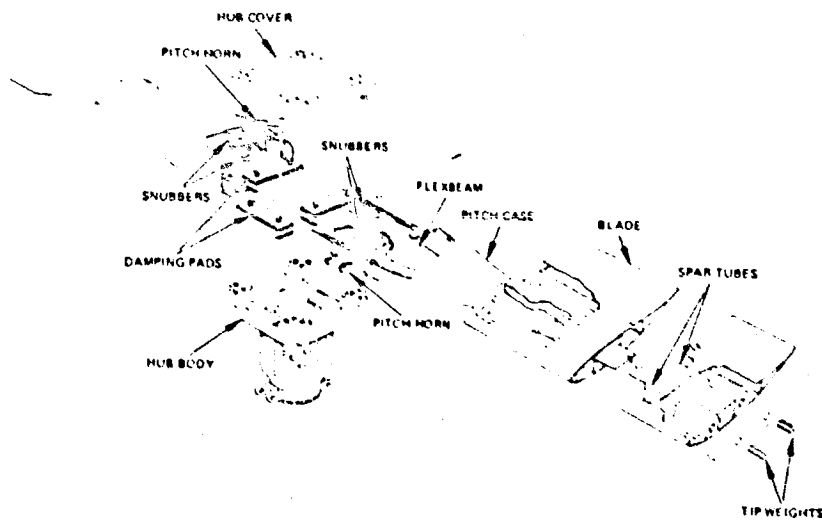
TAIL ROTOR

NASA
L-79-8772

FEATURES

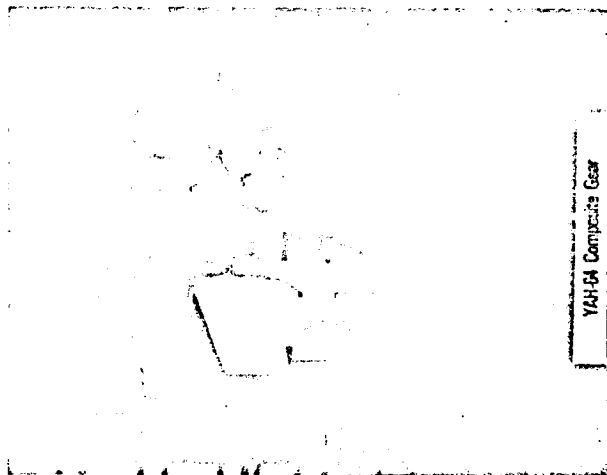
- 10% WEIGHT REDUCTION
- 20% COST REDUCTION
- REDUCED MAINTENANCE

YAH-64 Composite Tail Rotor



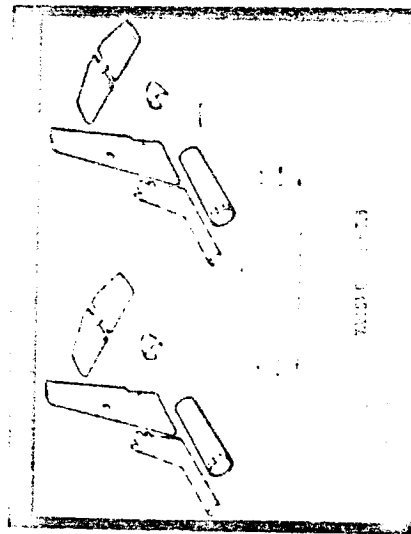
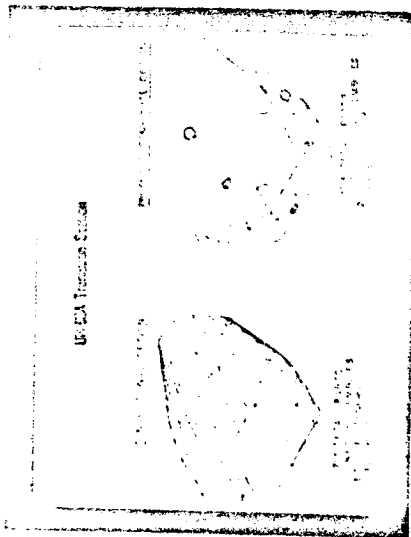
FORMULA PRODUCT

- 10% WEIGHT REDUCTION
- 25% COST REDUCTION
- FACILITATED CONSTRUCTION

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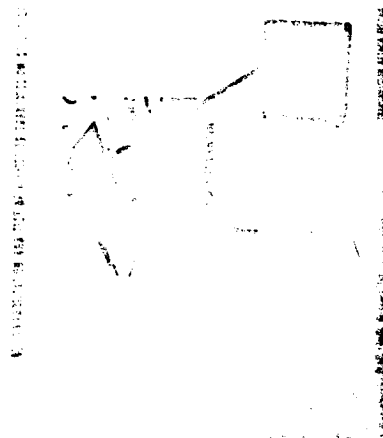
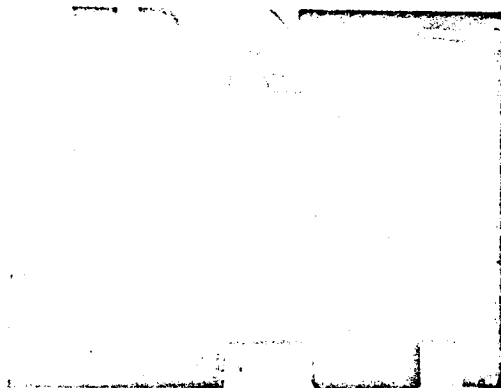
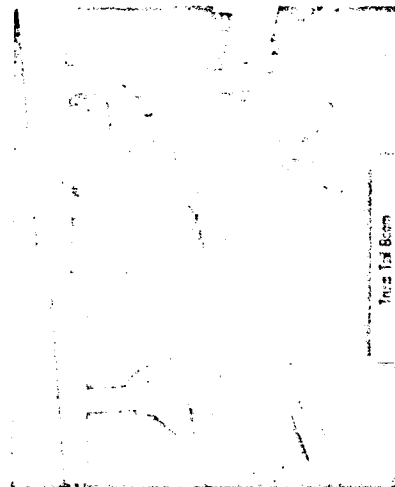
YAH-54 Composite Gear

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FOR THE PROJECT
 - 100% FULLY RESEARCH
 - 100% FULLY RESEARCH
 - 100% FULLY RESEARCH
 - 100% FULLY RESEARCH
 - 100% FULLY RESEARCH
 - 100% FULLY RESEARCH



ADVANCED AIRFRAME COMPOSITE STRUCTURES

• EMPHASIS ON FUSELAGE

- + 46% OF AIRCRAFT STRUCTURAL WEIGHT**
- + INCLUDES**
 - MAJOR LOAD PATHS**
 - CRASHWORTHINESS**
 - MAJOR JOINTS/HARD POINTS**
- + NO PRIOR MAJOR EFFORT IN THIS AREA**
- + LARGEST POTENTIAL FOR WEIGHT REDUCTION**

ADVANCED COMPOSITE AIRFRAME PROGRAM (ACAP)

OVERVIEW

Program Requirements

CURRENT - DAY SPECIFICATIONS

- STRUCTURAL DESIGN
- PERFORMANCE
- REPAIRABILITY, RELIABILITY & MAINTAINABILITY
- CRASHWORTHINESS
- BALLISTIC TOLERANCE
- DETECTABILITY

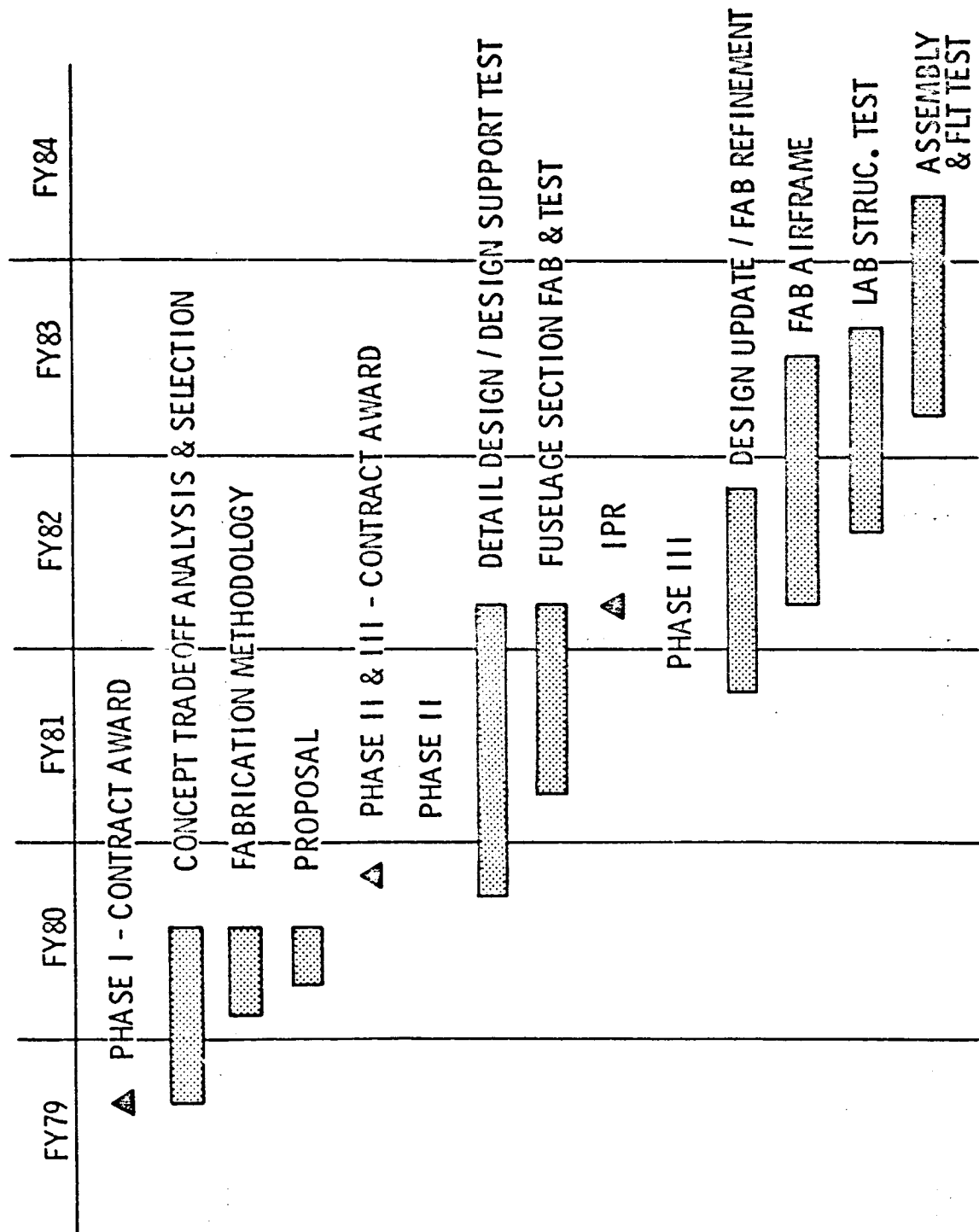
Program Goals

- 22% AIRFRAME WEIGHT SAVINGS
- 17% ACQUISITION COST REDUCTION
- 15% OPERATIONAL COST REDUCTION
- INCREASED DAMAGE TOLERANCE
- LOWER RADAR REFLECTIVITY
- IMPROVED R&M
- INCREASED FATIGUE USEFUL LIFE

Program Content

- PRELIMINARY DESIGN CONCEPTS
- DETAIL DESIGN
- DESIGN SUPPORT TESTING
- FULL-SCALE COMPONENT FABRICATION
- LABORATORY SUBSTANTIATION TESTING
- GROUND TESTING
- FLIGHT TESTING
- ANALYSIS OF RESULTS

ADVANCED COMPOSITE AIRFRAME PROGRAM



COMPOSITES TECHNOLOGY

FACTORS AFFECTING COMPOSITE POTENTIAL REALIZATION

- TECHNOLOGY HAS TO BE DEMONSTRATED TO THE USER, PRODUCER AND CERTIFIER
- COST PROHIBITS "CUT AND TRY" TECHNIQUES
- CONSERVATIVE FATIGUE AND DURABILITY DESIGN ALLOWANCES
- ANALYTICAL TECHNOLOGY NOT REFLECTED IN DESIGN TECHNIQUES
- ONE-FOR-ONE METAL REPLACEMENTS ARE PROHIBITIVE
- REDUCED ENERGY ABSORPTION AND IMPACT DAMAGE TOLERANCE
- STRUCTURAL OPTIMIZATION FOR STRENGTH AND DYNAMIC TUNING

Composites Session - Discussion

- . How can we better standardize on materials? With the present system, requalification results if a different manufacturer is used. The USAF design guide does not help, nor does the updated DOD-NASA advanced composite design guide.
- . The effect of environmental exposure, particularly moisture, on composites was debated. Many components have seen years of service without a problem, but any controlled tests show a significant degradation. Probably, lab tests are more severe than the real environment they simulate, and at the same time, early design applications were conservative enough so that some loss of properties was not enough to cause failures.
- . Why are composites so slow in being accepted? Answers offered were: cost; lack of expertise in using the materials, technological conservatism, lack of a "need" until fuel and strategic metals became scarce.
- . It was noted that NASA 's effort on R&D is on advanced composites, not the simpler application of fiberglass to replace metals.